AD-A157 685 PORTABLE DIAGNOSTIC RADIOMETER(U) DAVID SARNOFF RESEARCH CENTER PRINCETON NJ JUL 85 N00014-83-C-0524 1/1

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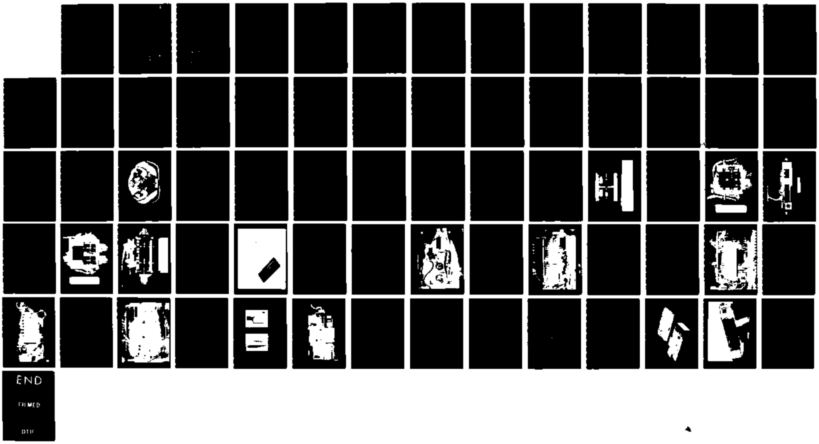

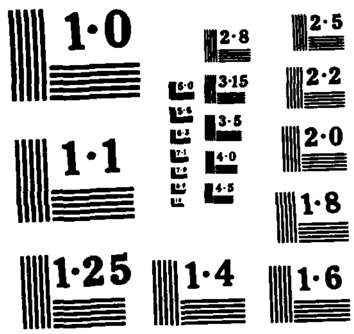


NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

AD-A157 685

PORTABLE DIAGNOSTIC RADIOMETER

FINAL REPORT - PHASE I

CONTRACT N00014-83-C-0524

PREPARED FOR

DEPARTMENT OF THE NAVY
NAVAL MEDICAL RESEARCH AND DEVELOPMENT COMMAND
NATIONAL NAVAL MEDICAL CENTER
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# PREFACE

This Final Report for Phase I was prepared by RCA Laboratories, Princeton, New Jersey under Contract No. N00014-83-C-0524 for the Naval Medical Research and Development Command, Bethesda, Maryland. The work on Phase I was performed from October 1, 1983 through June 30, 1984 at the RCA Microwave Technology Center, Dr. Fred Sterzer, Director. The program was supervised by Markus Nowogrodzki, Head of the Microwave Subsystems and Special Projects Group. The Project Scientist was Robert W. Paglione, Member of the Technical Staff, with technical support provided by Francis J. Wozniak and Eugene C. McDermott.

The computer modeling and other software support was provided by Morris Ettenberg, Consultant.

# I. INTRODUCTION

There exists a need for a portable diagnostic instrument that can noninvasively monitor and display internal body temperatures. This instrument would be extremely important on U.S. Navy ships whose complement does not include the services of competent medical professionals. In this case it would be important to determine whether a particular medical emergency does or does not exist in a patient. This would determine whether the patient should or should not be evacuated to a suitable medical facility for treatment.

The instrument would determine, by radiometric means, whether particular organs exhibit an elevated temperature. For example, this may be an aid in the diagnosis of appendicitis or nephritis.

The instrument described in this report is a dual-frequency microwave radiometer. The radiometer measures the amount of noise power being radiated from a localized tissue volume on the patient. The amplitude of this noise power over a frequency spectrum determined by the microwave components is proportional to the average temperature of the volume in question. Making this measurement at two separate frequencies can give an indication of the temperature profile over a depth as great as 6 cm.

## II. TECHNICAL DISCUSSION

### A. PROGRAM OBJECTIVE

The objective of Phase I of this program was to develop a "proof of concept" breadboard of a dual-frequency radiometer. The instrument should include a microprocessor, a readout, a power supply, and all circuits necessary to prove the concept of a self-balancing, multifrequency radiometer suitable for use as a diagnostic instrument by the U.S. Navy.

To meet this objective, the following tasks would be addressed:

1. Computer modeling of a multifrequency radiometer to determine the optimum frequencies that, when used with the portable radiometer, would provide temperature information at three body depths where hot-spots indicative of inflammation could be detected.

2. Adapting the self-balancing radiometer circuits to provide the multifrequency mode of operation determined from 1.

3. Construction of a breadboard instrument model.

4. Evaluation and testing of the experimental instrument of 3.

### B. COMPUTER MODELING

To be able to translate the multifrequency radiometric measurements of average temperature within a tissue volume into a three-point temperature profile, a computer model of the system and the resulting heat distributions as exhibited in particular radiometric measurements is required.

The computer program that has been developed calculates the

radiometric temperature at specified frequencies from a known temperature-versus-depth profile. The temperature profile is generated by assuming an arterial and ambient temperature and then calculating the heat transported due to the various heat conductivities and blood flows of the intervening tissue sections. The radiometric temperature is calculated in the following manner: The noise power, $P_n$, is calculated for a point on the temperature profile by multiplying the temperature, $T_n$, by Boltzmann's constant, k, and the receiver bandwidth, B. The amount of this power that reaches the surface is found by assuming an exponential decay with distance -- the exponential constant being the attenuation constant, , of the intervening tissues. The radiometric temperature is then the sum of all of the surface noise powers generated by all of the points on the profile divided by kB. Mathematically this is written as

1) $$T_{RAD} = T_1 \left\{1-\exp(-\alpha_1 \chi_1)\right\} + T_2 \left\{1 - \exp(-\alpha_2 \chi_2)\right\} \exp(-\alpha_1 \chi_1) + T_3 \left\{1-\exp(-\alpha_3 \chi_3)\right\} \exp\left\{-(\alpha_1 \chi_1 + \alpha_2 \chi_2)\right\} + \ldots T_n \left\{1-\exp(-\alpha_n \chi_n)\right\} \exp\left\{-\alpha_1 \chi_1 + \alpha_2 \chi_2 + \ldots \alpha_{n-1} \chi_{n-1})\right\}$$

where n = number of tissue sections

$\chi$ = thickness of tissue section

and $\alpha$ = attenuation constant of tissue section.

The curve in Fig. 1 was generated by using the computer model and by assuming an arterial temperature of 37°C and an ambient temperature of 21°C. The tissue geometry used was taken from a body slice in the area of the appendix.[1] This slice,

shown in Fig. 2, contains skin, fat, muscle, intestine, the appendix (processus vermiformis), and bone. The front-to-back tissue thicknesses used in the model are: 1mm-skin, 8.5mm-fat, 6.55cm-intestine, 1cm-appendix, 3.3cm-muscle, 5.1cm-bone, 1.4cm-muscle, 1.05cm-fat, and 6.5mm-skin. Typical values were used for the tissue density, thermal conductivity, specific heat, and blood flow.[2] Also, a value was used for normal surface cooling.[3] The curve in Fig. 1 is therefore a normal thermal profile in the appendix region. The radiometric temperature was calculated over the frequency range from 800 to 4000 MHz. The front surface reading is labeled TF(rad) in the figure, and only the 800 and 4000 MHz data are shown since the temperature function is linear between these two points.

In Fig. 3a, b, and c, the appendix has been given an elevated temperature of $2^{o}$ over normal; and the position of the appendix is varied from 4 to 8 cm. It can be seen from this data and the data in Fig. 1 that the radiometer must have an accuracy of $0.2^{o}C$ in order to detect a $2^{o}C$ elevated temperature at a depth of 6 cm.

In Fig. 4 and 5, the radiometric temperatures at 800 and 4000 MHz are plotted as a function of the surface temperature and hot-spot depth. The line representing no hot spot (NHS) is also shown in both figures. Therefore, from the measurement of the surface temperature and the radiometric temperature at 800 and 4000 MHz, it is possible to determine the depth of a typical hot spot. The temperature profile can then be extracted from the computer model. For example, if the surface and radiometric

temperatures are 33.7°C, 36.7°C at 800 MHz, and 36.1°C at 4000 MHz; then the hot spot occurs at a depth of 4 cm. The temperature profile for this condition is as shown in Fig. 2b; and the three temperatures that would be displayed are 34.7°C at 0 cm depth, 37°C at 2 cm depth, and 38.7° at 4 cm depth.

C. 4 GHz SUBSYSTEM

The basic Dicke-type radiometer[4] is shown schematically in Fig. 6. In this circuit, the target noise power entering through the antenna is compared to the noise power eminating from a temperature-controlled termination. The difference between the two signal levels is displayed on the DC meter--this reading is proportional to the temperature of the target. An improvement can be made in the accuracy of this system if the reference noise signal, in this case the oven-controlled termination, was always adjusted to give a zero reading on the DC meter; then the temperature of the reference noise source would be equal to the temperature of the target. This self-balancing scheme can be realized by replacing the over-controlled termination with a diode noise source. The mixer can also be replaced with a synchronous detector to improve the system sensitivity and reduce the system noise.

The single-throw-double-pole switch is usually realized with an electronically-switched, latching ferrite circulator; however, at these frequencies, the size, weight and current drawn by these components are limiting factors when considering a portable instrument. The switch can also be designed using switched low-noise amplifiers, as shown in Fig. 7. Each amplifier is pulsed

on and off asynchronously with the other, and the off-channel isolation is greater than 40 dB. The output of each amplifier is combined through a 3 dB hybrid coupler to produce a single switched output.

The amplifiers were designed around the NE13783-4 field-effect transistor--these transistors are optimized for low-noise performance at 4 GHz. The scattering parameters of these devices were measured with a computer-controlled automatic network analyzer. Input and output matching networks were designed that would produce an amplifier with a minimum gain of 13 dB from 3.7 to 4.2 GHz. The amplifiers were assembled on pallets and tested. A photograph of an amplifier pallet is shown in Fig. 8 and the measured gain of a typical amplifier is shown in Fig. 9. The assembled switch and amplifier are shown in the photographs of Figs. 10 and 11. The gain of the 3-stage amplifier with isolators is shown in Fig. 12.

D. 800 MHz SUBSYSTEM

The 800 MHz amplifier and switch were designed in a similar manner as the 4 GHz amplifiers. The solid-state devices used in this case were AT-41470 low-noise bipolar transistors. A photograph of the switch and amplifier is shown in Fig. 13 and 14. The gain response of the 2-stage amplifier is shown in Fig. 15.

E. ANTENNAS

Folded-dipole antennas were chosen for the radiometer since they can easily be made on a printed-circuit board, they can be made balanced, and they operate over a wide bandwidth.[5] A

photograph of the 800 and 4000 MHz antenna assembly is shown in Fig. 16. Each antenna on the antenna board, also shown in Fig. 16, is connected to a 3.6mm coaxial line that protrudes out the back of the drawn-aluminum housing. The antenna board is mounted within the housing at a distance of 1.6mm from the open end. The 1.6mm gap is filled with a layer of neoprene rubber foam that acts as a thermal insulator. A 300K-ohm thermistor (Victory Engineering, Model 53A55) is epoxied into the antenna board so that it protrudes slightly through the foam rubber to contact the tissues being measured. The thermistor wires also come out the back of the aluminum housing.

The back of the aluminum housing also acts as the reflecting backplane for the 800 MHz antenna; a brass plate (38.1mm wide x 16.5mm high x 0.8mm thick) mounted on the coaxial line of the 4 GHz antenna at a distance of 10 cm from the rear of the antenna board acts as its reflecting backplane.

The VSWR of these antennas measured while the assembly is in contact with tissue is shown in Fig. 17.

F. LOW-FREQUENCY COMPONENTS

The schematic for the dual-frequency radiometer, including the low-frequency and digital components, is shown in Fig. 18. the low-frequency components consist of a 100 Hz modulator, a filter/amplifier, a synchronous detector and loop amplifier, a pulse-width modulator, and a switching regulator.

A photograph of the 100 Hz modulator and its associated schematic are shown in Figs. 19 and 20. This circuit produces a 200 Hz, crystal-controlled square-wave that is divided by a flip-

flop to achieve a 100 Hz modulation frequency. IC3 and Q5, and IC4 and Q6 produce 10 V pulses capable of driving 20 ma to the collector of each bipolar amplifier stage in the 800 MHz switch. Q3 and Q4 provide the same function for the 4000 MHz switch with 3 V pulses driving 10 ma to the drains of the FET amplifiers. Q1 and Q2 provide a slow-turn-on 3.6 V supply for Q3 and Q4.

The filter/amplifier is shown in the photograph of Fig. 21 and schematically in Fig. 22. All ICs are OP-27 low-noise operational amplifiers. The first stage is a buffer stage that provides AC coupling, transient protection, and a DC return path for the active filter. The second stage is the active filter with a gain and cutoff frequency of approximately 3 dB and 1 KHz.

The third stage is a variable-gain amplifier that provides 0 to 40 dB of gain. The filter response at full gain for the entire circuit is shown in Fig. 23.

The photograph and schematic for the synchronous detector and loop amplifier are shown in Figs. 24 and 25. The synchronous detector is built around the AD630 balanced modulator/demodulator chip, connected as an in-phase detector. In this mode the AD630 will produce a DC output voltage that is proportional to the difference between the two input signals when the two input signals are in phase with the reference signal, which in this case is the 100 Hz modulation to the switches. Therefore, any system noise that has been impressed on either or both inputs is greatly reduced and the overall detection sensitivity is greatly increased.

IC3 in Fig. 25 is the loop amplifier. The amplifier is an

integrator with a time constant of approximately 3 seconds. The op-amp is connected in the inverting mode so that when the input voltage goes negative (this is indicative of an increasing target temperature), the output goes positive. A change in the output voltage of the loop amplifier causes a change in the noise power out of the noise diode which in turn brings the input voltage to zero or into a balanced loop condition.

The pulse-width modulator board is shown in the photograph of Fig. 26 and schematically in Fig. 27. The CA1524 outputs 28 V pulses at a 1 KHz repetition rate to the diode noise source. The pulse width of these pulses varies between 0 and 100% as the control voltage varies between 1 and 3.5 V. The DC average of these pulses is proportional to the target temperature, and it is this voltage that is read by the microprocessor and converted into temperature.

Most of the DC voltages required by the various components in the radiometer system are supplied by the switching regulator shown in the photograph of Fig. 28 and the schematic of Fig. 29. The power supply was designed to operate with a +12 VDC input which would be supplied by a rechargeable battery in Phase II. The FET bias voltages, that is the -5 V gate supply and +3 V drain supply, are sequenced such that on turn-on the gate voltage is on before the drain voltage and on turn-off the gate is off after the drain voltage. The turn-on and turn-off sequencing can be seen in the oscillographs of Fig. 30a and b.

## G. DIGITAL PROCESSOR SUBSYSTEM

The digital processor subsystem is shown in the photograph

# FIGURE CAPTIONS

Fig. 1. Temperature-versus-depth profile in tissue calculated using assumed arterial and ambient temperatures of 37 and 21$^{o}$C. The tissue geometry is that of a body slice in the area of the appendix. TF(rad) is the radiometric temperature measured at a depth of 0 cm.

Fig. 2. A 2.5 cm thick body slice in the area of the appendix (12 Processus vermiformis).

Fig. 3. Temperature profile in tissue calculated using assumed arterial and ambient temperatures of 37 and 21$^{o}$C. An elevated temperature of 2$^{o}$C, representing an inflamed appendix, is calculated for depths of (a) 4 cm, (b) 6 cm, and (c) 8 cm.

Fig. 4. The calculated radiometric temperature as a function of surface temperature and hot-spot depth for an 800 MHz radiometer.

Fig. 5. The calculated radiometric temperature as a function of surface temperature and hot-spot depth for a 4 GHz radiometer.

Fig. 6. Basic Dicke radiometer schematic.

Fig. 7. Schematic of a single-pole-double-throw (SPDT) microwave switch using low-noise amplifiers.

Fig. 8. Photograph of the NE13783-4 low-noise amplifier pallet.

Fig. 9. Measured gain of a typical NE13783-4 amplifier pallet.

Fig. 10. Photograph of the assembled FET SPDT switch.

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```
01B1 27                   DEC   R7
01B2 27                   DEC   R7
01B3 F80B                 LDI   0BH
01B5 5F                   STR   RF
01B6 F8CB                 LDI   0CBH
01B8 53                   STR   R3
01B9 F8FC                 LDI   0FCH
01BB 59                   STR   R9
01BC F85E                 LDI   5EH
01BE 54                   STR   R4
01BF F801                 LDI   01H
01C1 55                   STR   R5
01C2 C0005o  >            LBR   LP1
01C5 7B           CHK2    SEQ         ;IF LOOP CNTR=2
01C6 DE                   SEP   RE    ;SET RF SWITCHES FOR 800MHZ
01C7 27                   DEC   R7    ;CALL DELAY & RETURN
01C8 27                   DEC   R7
01C9 27                   DEC   R7
01CA F806                 LDI   06H
01CC 5F                   STR   RF
01CD F865                 LDI   65H
01CF 53                   STR   R3
01D0 F8CF                 LDI   0CFH
01D2 59                   STR   R9
01D3 F801                 LDI   01H
01D5 55                   STR   R5
01D6 F822                 LDI   22H
01D8 54                   STR   R4
01D9 C0005o  >            LBR   LP1
                  ;**
01DC 60           EXDLY   IRX
01DD D0                   SEP   R0
01DE F8CF         DELAY   LDI   0CFH
01E0 26                   DEC   R6
01E1 56                   STR   R6
01E2 26                   DEC   R6
01E3 56                   STR   R6
01E4 F801         PT1     LDI   01H
01E6 F5                   SD
01E7 56                   STR   R6
01E8 60                   IRX
01E9 F800                 LDI   00H
01EB 75                   SDB
01EC 56                   STR   R6
01ED 32DC    >            BZ    EXDLY
01EF 26                   DEC   R6
01F0 30E4    >            BR    PT1
01F2 DE           QUIT    SEP   RE
01F3 DE                   SEP   RE
01F4 C00000  >            LBR   START
```

```
 0175 57          STR   R7     ;STORE 2nd DIGIT IN R7-1
 0176 6E          INP   6
 0177 27          DEC   R7
 0178 57          STR   R7     ;STORE LS DIGIT IN R7-2
              ;**DISPLAY DIGITS
 0179 F84F        LDI   4FH    ;DISABLE CDP1855, ENABLE CDP1851
 017B 26          DEC   R6
 017C 56          STR   R6
 017D F833        LDI   33H
 017F 26          DEC   R6
 0180 56          STR   R6
 0181 F808        LDI   08H
 0183 26          DEC   R6
 0184 56          STR   R6
 0185 61          OUT   1
 0186 62          OUT   2
 0187 62          OUT   2
              ;**
 0188 07          LDN   R7     ;LOAD LS THRU MS DIGIT
 0189 26          DEC   R6
 018A 56          STR   R6
 018B 17          INC   R7
 018C 07          LDN   R7
 018D 26          DEC   R6
 018E 56          STR   R6
 018F 17          INC   R7
 0190 07          LDN   R7
 0191 26          DEC   R6
 0192 56          STR   R6
 0193 64          OUT   4
 0194 26          DEC   R6
 0195 63          OUT   3
 0196 64          OUT   4
 0197 26          DEC   R6
 0198 65          OUT   5
 0199 64          OUT   4
 019A 26          DEC   R6
 019B 67          OUT   7
 019C DE          SEP   RE     ;CALL DELAY
              ;**MAIN LOOP CNTR TEST
 019D 0D          LDN   RD     ;LOAD CNTR & SUBTRACT 1
 019E FF01        SMI   01H
 01A0 32F2        BZ    QUIT   ;IF LOOP CNTR=0 THEN END
 01A2 5D          STR   RD
 01A3 FF01        SMI   01H
 01A5 3AC5        BNZ   CHK2   ;IF LOOP CNTR=1
 01A7 F820        LDI   20H    ;SET MUX CHNL=2 & RETURN
 01A9 5A          STR   RA
 01AA F8A0        LDI   0A0H
 01AC 5B          STR   RB
 01AD F830        LDI   30H
 01AF 5C          STR   RC
 01B0 27          DEC   R7
```

```
0139 07       LDN  R7
013A 26       DEC  R6
013B 56       STR  R6
013C F864     LDI  64H
013E 26       DEC  R6
013F 56       STR  R6
0140 F8FC     LDI  0FCH
0142 26       DEC  R6
0143 56       STR  R6
0144 67       OUT  7
0145 64       OUT  4
0146 65       OUT  5
0147 66       OUT  6
0148 67       OUT  7
0149 C4       NOP
014A C4       NOP
014B C4       NOP
014C F8F0     LDI  0F0H
014E 26       DEC  R6
014F 56       STR  R6
0150 67       OUT  7
0151 6C       INP  4
0152 6D       INP  5
0153 17       INC  R7
0154 57       STR  R7     ;STORE MS DIGIT IN R7
0155 6E       INP  6
0156 27       DEC  R7
0157 57       STR  R7     ;STORE REMAINDER IN R7-1
0158 F8F2     LDI  0F2H   ;DIVIDE REMAINDER BY 10 (0AH)
015A 26       DEC  R6
015B 56       STR  R6
015C 07       LDN  R7
015D 26       DEC  R6
015E 56       STR  R6
015F F80A     LDI  0AH
0161 26       DEC  R6
0162 56       STR  R6
0163 F8FC     LDI  0FCH
0165 26       DEC  R6
0166 56       STR  R6
0167 67       OUT  7
0168 64       OUT  4
0169 65       OUT  5
016A 67       OUT  7
016B C4       NOP
016C C4       NOP
016D C4       NOP
016E F8F0     LDI  0F0H
0170 26       DEC  R6
0171 56       STR  R6
0172 67       OUT  7
0173 6C       INP  4
0174 6D       INP  5
```

```
00FC 09                 LDN     R9
00FD 26                 DEC     R6
00FE 56                 STR     R6
00FF F8F0               LDI     0F0H
0101 26                 DEC     R6
0102 56                 STR     R6
0103 67                 OUT     7
0104 64                 OUT     4
0105 67                 OUT     7
0106 C4                 NOP
0107 C4                 NOP
0108 C4                 NOP
0109 F8F0               LDI     0F0H
010B 26                 DEC     R6
010C 56                 STR     R6
010D 67                 OUT     7
010E 26                 DEC     R6
010F 6C                 INP     4
0110 6E                 INP     6       ;INPUT BYTE TO STACK
0111 6D                 INP     5
0112 60                 IRX             ;COMPLEMENT IF NEG AT C1
0113 F800               LDI     00H
0115 56                 STR     R6
0116 26                 DEC     R6
0117 17                 INC     R7
0118 07                 LDN     R7
0119 FFFF               SMI     0FFH
011B 27                 DEC     R7
011C 3A29   >           BNZ     C2
011E F0                 LDX
011F FBFF               XRI     0FFH
0121 FC01               ADI     01H
0123 56                 STR     R6
0124 60                 IRX
0125 F8FF               LDI     0FFH
0127 56                 STR     R6
0128 26                 DEC     R6
0129 04         C2      LDN     R4      ;ADD CONSTANT
012A F4                 ADD
012B 57                 STR     R7
012C 60                 IRX
012D 05                 LDN     R5
012E 74                 ADC
012F 17                 INC     R7
0130 57                 STR     R7
                ;**CONVERT TO DECIMAL DIGITS
0131 F8F2               LDI     0F2H    ;DIVIDE BY 100 (64H)
0133 26                 DEC     R6
0134 56                 STR     R6
0135 07                 LDN     R7
0136 26                 DEC     R6
0137 56                 STR     R6
0138 27                 DEC     R7
```

```
00BF 60                 IRX
                  ;**CONVERT AVERAGE TO TEMPERATURE
00C0 27                 DEC     R7      ;SUBTRACT CONSTANT FROM AVG.
00C1 07                 LDN     R7
00C2 56                 STR     R6
00C3 03                 LDN     R3
00C4 F5                 SD
00C5 57                 STR     R7
00C6 17                 INC     R7
00C7 07                 LDN     R7
00C8 56                 STR     R6
00C9 0F                 LDN     RF
00CA 75                 SDB
00CB 57                 STR     R7
00CC 07                 LDN     R7      ;COMPLEMENT IF SUBTR. GOES NEG.
00CD FFFF               SMI     0FFH
00CF 3AD9    >          BNZ     C1
00D1 27                 DEC     R7
00D2 07                 LDN     R7
00D3 FBFF               XRI     0FFH
00D5 FC01               ADI     01H
00D7 57                 STR     R7
00D8 17                 INC     R7
00D9 F8FC       C1      LDI     0FCH    ;DISABLE CDP1851, ENABLE CDP1855,
00DB 26                 DEC     R6      ;& INITIALIZE
00DC 56                 STR     R6
00DD F800               LDI     00H
00DF 26                 DEC     R6
00E0 56                 STR     R6
00E1 61                 OUT     1
00E2 67                 OUT     7
00E3 F8F9               LDI     0F9H
00E5 26                 DEC     R6
00E6 56                 STR     R6
00E7 27                 DEC     R7
00E8 07                 LDN     R7      ;LOAD X & Z REGS. & MULT. BY 93 (5DH)
00E9 26                 DEC     R6
00EA 56                 STR     R6
00EB F85D               LDI     5DH
00ED 26                 DEC     R6
00EE 56                 STR     R6
00EF 64                 OUT     4
00F0 65                 OUT     5
00F1 67                 OUT     7
00F2 C4                 NOP
00F3 C4                 NOP
00F4 C4                 NOP
00F5 6C                 INP     4
00F6 6D                 INP     5
00F7 6E                 INP     6
00F8 F8F2               LDI     0F2H    ;LOAD X REG. & DIVIDE BY CONSTANT
00FA 26                 DEC     R6
00FB 56                 STR     R6
```

```
0082 FA0F                  ANI     0FH     ;MASK OUT BITS 5-8
0084 57                    STR     R7
0085 0C                    LDN     RC      ;GIVE TOGGLE COMMAND
0086 FF10                  SMI     10H
0088 26                    DEC     R6
0089 56                    STR     R6
008A 0C                    LDN     RC
008B 26                    DEC     R6
008C 56                    STR     R6
008D 64                    OUT     4
008E 64                    OUT     4
008F 6E                    INP     6       ;INPUT A-TO-D BITS 5,6,7,8,9,10,11,12
0090 60                    IRX
0091 F4                    ADD             ;ADD PRESENT READING TO PREVIOUS
0092 56                    STR     R6
0093 60                    IRX
0094 07                    LDN     R7
0095 74                    ADC
0096 56                    STR     R6
0097 26                    DEC     R6
0098 08                    LDN     R8      ;SUBTRACT 01H FROM LOOP COUNTER (R8)
0099 FF01                  SMI     01H
009B 32A1     >            BZ      DIVN    ;CHECK IF 16 RDNGS HAVE BEEN TAKEN
009D 58                    STR     R8
009E C0006E   >            LBR     AVG
                     ;**
00A1 F0              DIVN  LDX             ;DIVIDE SUM OF 16 NOS. BY 16
00A2 F6                    SHR
00A3 F6                    SHR
00A4 F6                    SHR
00A5 F6                    SHR
00A6 56                    STR     R6
00A7 60                    IRX
00A8 F0                    LDX
00A9 FE                    SHL
00AA FE                    SHL
00AB FE                    SHL
00AC FE                    SHL
00AD 26                    DEC     R6
00AE F1                    OR
00AF FBFF                  XRI     0FFH    ;COMPLEMENT LS BYTE
00B1 27                    DEC     R7
00B2 57                    STR     R7
00B3 17                    INC     R7
00B4 60                    IRX
00B5 F0                    LDX
00B6 F6                    SHR
00B7 F6                    SHR
00B8 F6                    SHR
00B9 F6                    SHR
00BA FBFF                  XRI     0FFH    ;COMPLEMENT MS BYTE
00BC FA0F                  ANI     0FH     ;MASK OUT MS BITS
00BE 57                    STR     R7
```

```
0048 F801                LDI     01H
004A 55                  STR     R5
004B F812                LDI     12H
004D 53                  STR     R3
                   ;**BEGIN MEASUREMENT LOOP
004E 7A                  REQ             ;SET RF SWITCHES TO 4GHZ
004F F801                LDI     01H     ;SET RETURN ADDRESS
0051 BE                  PHI     RE
0052 F8DE                LDI     0DEH
0054 AE                  PLO     RE
0055 DE                  SEP     RE      ;CALL DELAY SUBR.
                   ;**
0056 F84F          LP1   LDI     4FH     ;ENABLE CDP1851
0058 26                  DEC     R6      ;SET PORT B TO INPUT
0059 56                  STR     R6      ;SET PORT A TO OUTPUT
005A F833                LDI     33H
005C 26                  DEC     R6
005D 56                  STR     R6
005E F808                LDI     08H
0060 26                  DEC     R6
0061 56                  STR     R6
0062 61                  OUT     1
0063 62                  OUT     2
0064 62                  OUT     2
                   ;**
0065 F800                LDI     00H     ;INITIALIZE STACK TO 0
0067 26                  DEC     R6
0068 56                  STR     R6
0069 26                  DEC     R6
006A 56                  STR     R6
006B F810                LDI     10H     ;INITIALIZE R8 TO 16
006D 58                  STR     R8
                   ;**
006E 0C            AVG   LDN     RC      ;SET CD4066 INPUT MUX TO
006F FF10                SMI     10H     ;INPUT CHANNEL 1 OR 2,
0071 26                  DEC     R6      ;GIVE A-TO-D CONVERT COMMAND,
0072 56                  STR     R6      ;RESET CD4013 TOGGLE FF
0073 0C                  LDN     RC      ;GIVE TOGGLE COMMAND TO
0074 26                  DEC     R6      ;CD4013 TOGGLE FF
0075 56                  STR     R6
0076 0B                  LDN     RB
0077 26                  DEC     R6
0078 56                  STR     R6
0079 0A                  LDN     RA
007A 26                  DEC     R6
007B 56                  STR     R6
007C 64                  OUT     4
007D 64                  OUT     4
007E 64                  OUT     4
007F 64                  OUT     4
                   ;**
0080 26                  DEC     R6      ;INPUT A-TO-D BITS 5,6,7,8,1,2,3,4
0081 6E                  INP     6       ;[MSB=BIT 1, LSB=BIT 12]
```

```
                        ;**INITIALIZE REGISTERS           *****PROGRAM BOB*****
0000 F84F          START     LDI    4FH     ;SET MS BYTE OF RAM TO 4FH
0002 B3                      PHI    R3
0003 B4                      PHI    R4
0004 B5                      PHI    R5
0005 B6                      PHI    R6
0006 B7                      PHI    R7
0007 B8                      PHI    R8
0008 B9                      PHI    R9
0009 BA                      PHI    RA
000A BB                      PHI    RB
000B BC                      PHI    RC
000C BD                      PHI    RD
000D BF                      PHI    RF
000E F880                    LDI    80H     ;R6 ADDRESS=4F80H <<STACK>>
0010 A6                      PLO    R6
0011 E6                      SEX    R6      ;SET STACK TO R6
0012 F810                    LDI    10H     ;R7 ADDRESS=4F10H <<TEMP. DATA>>
0014 A7                      PLO    R7
0015 F800                    LDI    00H     ;R8 ADDRESS=4F00H <<AVG. LOOP CNTR.>>
0017 A8                      PLO    R8
0018 F820                    LDI    20H     ;RA ADDRESS=4F20H <<MUX CHNL COMMAND>>
001A AA                      PLO    RA
001B F830                    LDI    30H     ;RB ADDRESS=4F30H <<CONVERT COMMAND>>
001D AB                      PLO    RB
001E F840                    LDI    40H     ;RC ADDRESS=4F40H <<TOGGLE COMMAND>>
0020 AC                      PLO    RC
0021 F850                    LDI    50H     ;RD ADDRESS=4F50H <<MAIN LOOP CNTR>>
0023 AD                      PLO    RD
0024 F860                    LDI    60H     ;RF ADDRESS=4F60H <<MATH CONSTANT>>
0026 AF                      PLO    RF
0027 F861                    LDI    61H     ;R9 ADDRESS=4F61H <<MATH CONSTANT>>
0029 A9                      PLO    R9
002A F862                    LDI    62H     ;R5 ADDRESS=4F62H <<MATH CONSTANT>>
002C A5                      PLO    R5
002D F863                    LDI    63H     ;R4 ADDRESS=4F63H <<MATH CONSTANT>>
002F A4                      PLO    R4
0030 F864                    LDI    64H     ;R3 ADDRESS=4F64H <<MATH CONSTANT>>
0032 A3                      PLO    R3
0033 F800                    LDI    00H     ;INITIALIZE RA TO MUX CHNL 1
0035 5A                      STR    RA
0036 F880                    LDI    80H     ;INITIALIZE CONVERT COMMAND
0038 5B                      STR    RB
0039 F810                    LDI    10H     ;INITIALIZE TOGGLE COMMAND
003B 5C                      STR    RC
003C F803                    LDI    03H     ;INITIALIZE MAIN LOOP CNTR TO 3
003E 5D                      STR    RD
003F F807                    LDI    07H
0041 5F                      STR    RF
0042 F89E                    LDI    9EH
0044 59                      STR    R9
0045 F810                    LDI    10H
0047 54                      STR    R4
```

## J. PLANS FOR PHASE-II

The prototype unit will be delivered under Phase II of the program. A photograph of the shell of the planned prototype is shown in Fig. 38. Not shown in the photograph is the 12 volt, 3 amp-hour battery and charger unit that will connect to the pistol grip.

The display on the rear panel of the unit is a 16-character liquid-crystal display that will simultaneously display the three temperatures corresponding to the temperature of the surface and the temperature at two depths.

| | 4 GHz HEX (Decimal) | 800 MHz HEX (Decimal) | Thermistor HEX (Decimal) |
|---|---|---|---|
| C1 | 64 ( 100) | 64 ( 100) | 64 ( 100) |
| C2 | 959 (2393) | A77 (2679) | BF5 (3100) |
| C3 | 73 ( 115) | BE ( 190) | F1 ( 241) |
| C4 | 140 ( 320) | 140 ( 320) | 12B ( 299) |

For the above constants, the 800 MHz radiometer will resolve temperatures between 18.5 and 45.4°C; the 4 GHz radiometer between 9.8 and 54.1°C; and the thermistor between 19.3 and 40.4°C.

## I. RADIOMETER EVALUATION

$$\text{Next Significant Digit (NSD)} = \frac{R1}{10} = D2+R2$$

Least Significant Digit (LSD) = R2.

D1, D2 and R2 are then displayed on the liquid crystal display.

The Q lines are next set to switch the latching switches into the 800 MHz position; and, with different constants in eqn. 2, a new temperature is measured and displayed. Finally the surface thermistor is interfaced to the A-to-D through a buffer amplifier and the multiplexer, and the surface temperature is calculated and displayed in a similar manner. The flow chart for the above sequence is shown in Fig. 36.

The source file that contains the assembly code for the radiometer system is listed in Appendix A.

## H. BREADBOARD

The breadboard unit is shown in Fig. 37. The unit was calibrated by placing the antenna in contact with saline that was maintained at various temperatures. The antenna housing was covered with a thin layer of plastic food wrap for the calibration procedure. The saline was contained in a galvanized steel pail whose inside surfaces were lined with a 1/4 inch thick carbon-impregnated foam material. The lossy foam essentially makes the pail of saline appear as an infinite volume at a known temperature.

The radiometer and thermistor voltages were recorded for saline temperatures of 24 and 40$^{o}$C. The constants of the linearizing equation (eqn. 2) are:

of Fig. 31. It consists of a power supply ($\pm$15 V and +5 V), a CDP18S601 microboard computer, a multiply/divide unit, and an interface and display board.

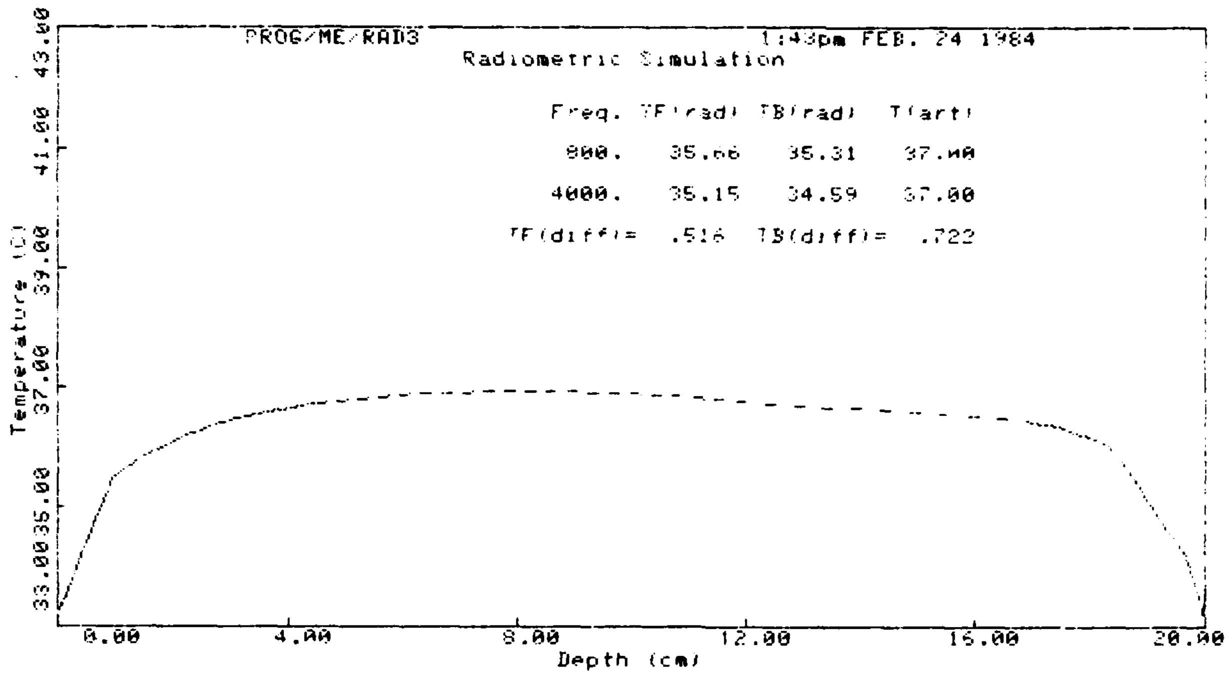
The CDP18S601 card contains a CDP1802 CPU, a 2 MHz crystal-controlled clock, read-write memory, parallel I/O ports, and sockets for up to 8 kilobytes of EPROM. The layout of the major components on this card is shown in Fig. 32. The CDP1855 multiply/divide unit is located between the CDP18S601 and the interface card. The schematic for this device is shown in Fig. 33. The schematic for the interface and display card is shown in Fig. 34, and the respective card interconnection diagram is shown in Fig. 35.

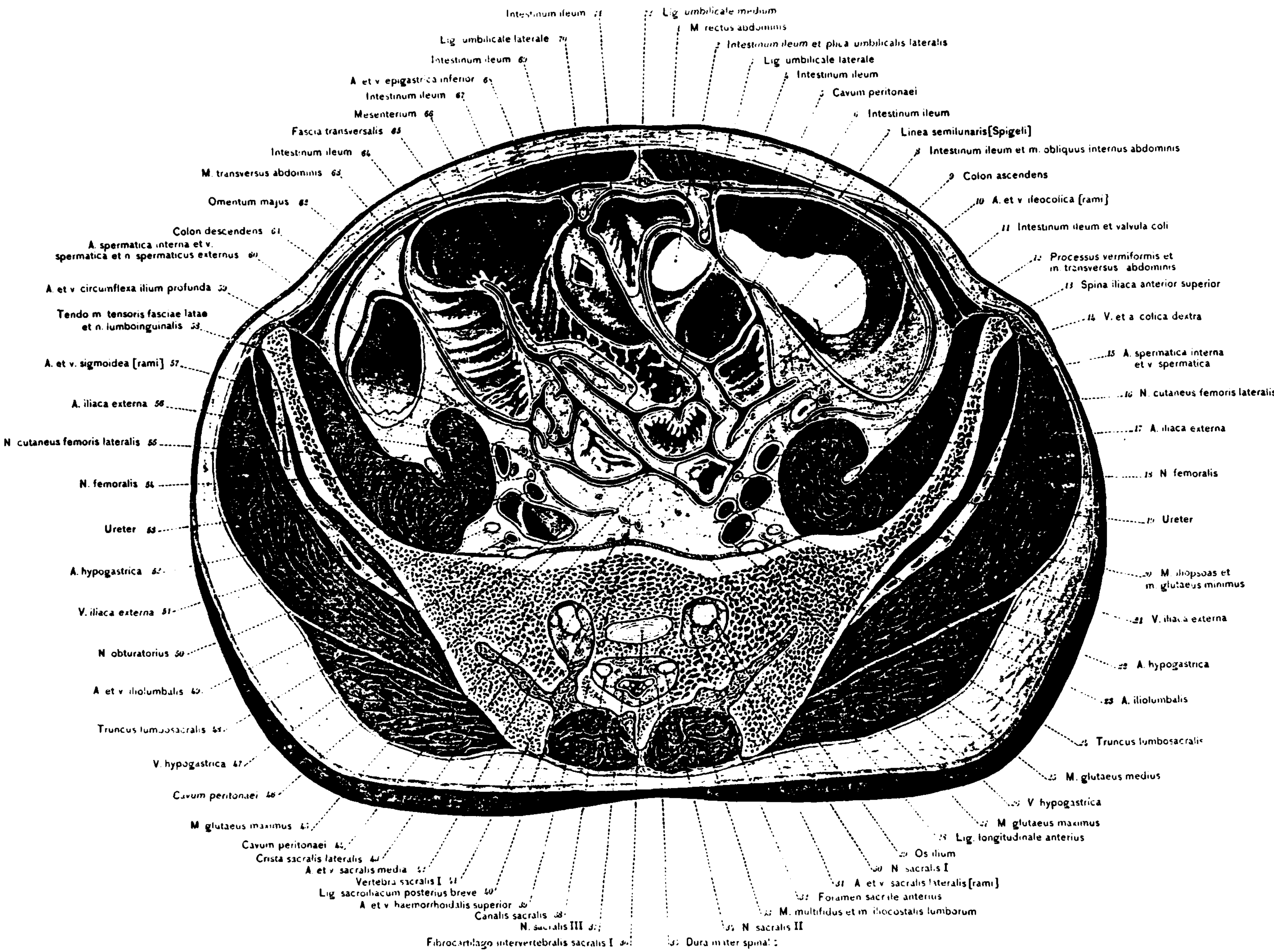
The subsystem operation is basically as follows: On start-up, the CPU resets the Q line (P1-6) which sets the latching switches (see Fig. 18) to the 4 GHz radiometer position. The radiometer output voltage is connected to the 12-bit A-to-D converter on the interface card through a buffer amplifier and the input multiplexer. The CPU converts the 12-bit digital code into a temperature using

$$2) \quad T = \frac{C1*(N-C2)}{C3} + C4$$

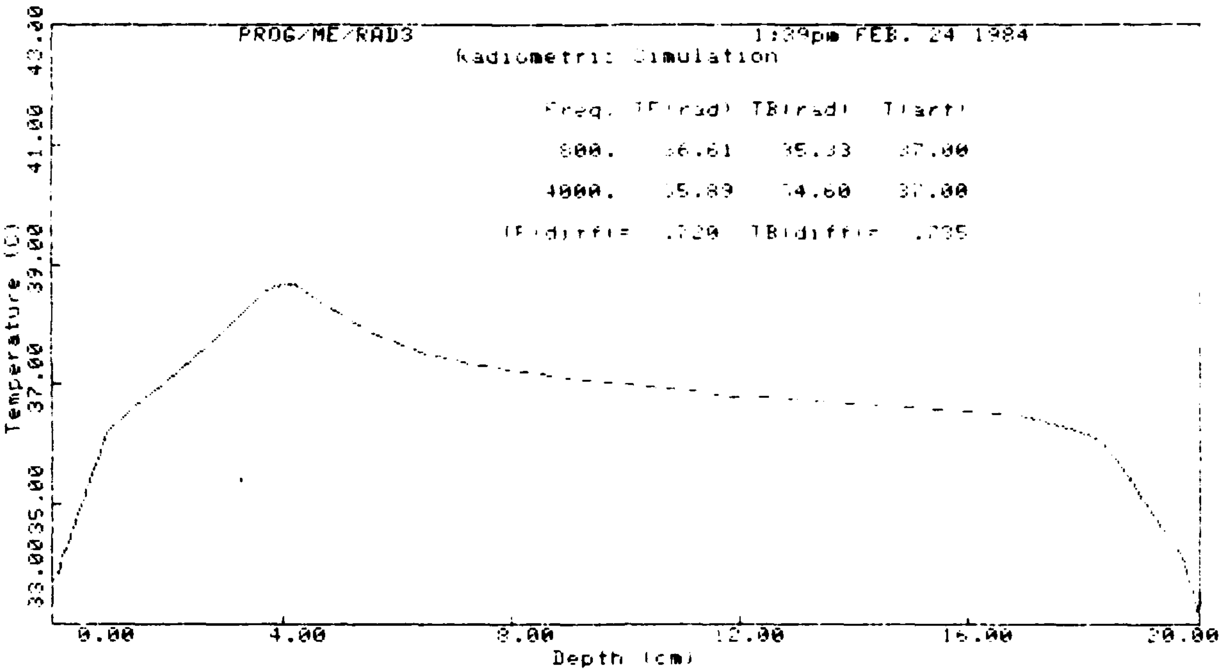
where N = 12-bit digital number in hexadecimal and C1 through C4 are constants. The temperature, T, calculated in eqn. 2 is in hexadecimal and must be converted to decimal digits for display. This is accomplished by using the following

3) Most Significant Digit (MSD) $= \frac{T}{100} =$ DIGIT 1(D1)+Remainder 1 (R1)

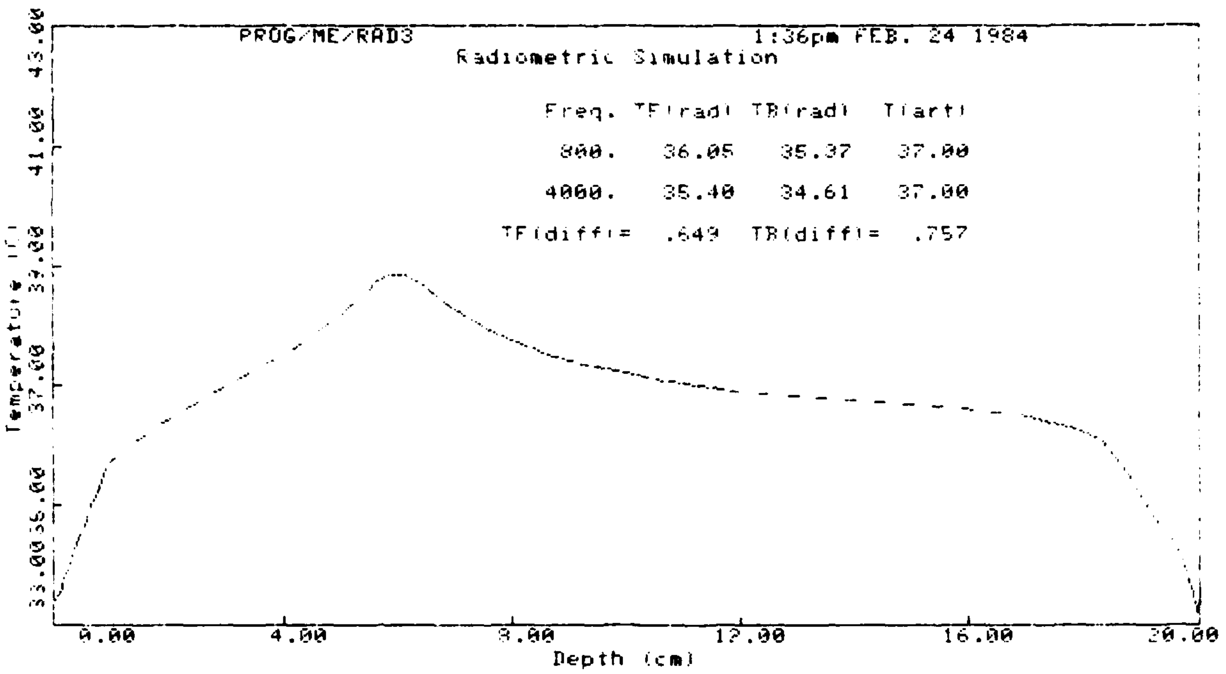

PROG/ME/RAD3
1:43pm FEB. 24 1984
Radiometric Simulation
Freq. TF(rad) TB(rad) T(art)
800. 35.66 35.31 37.00
4000. 35.15 34.59 37.00
TF(diff)= .516 TB(diff)= .722
Temperature (C)
33.00
35.00
37.00
39.00
41.00
43.00
0.00
4.00
8.00
12.00
16.00
20.00
Depth (cm)

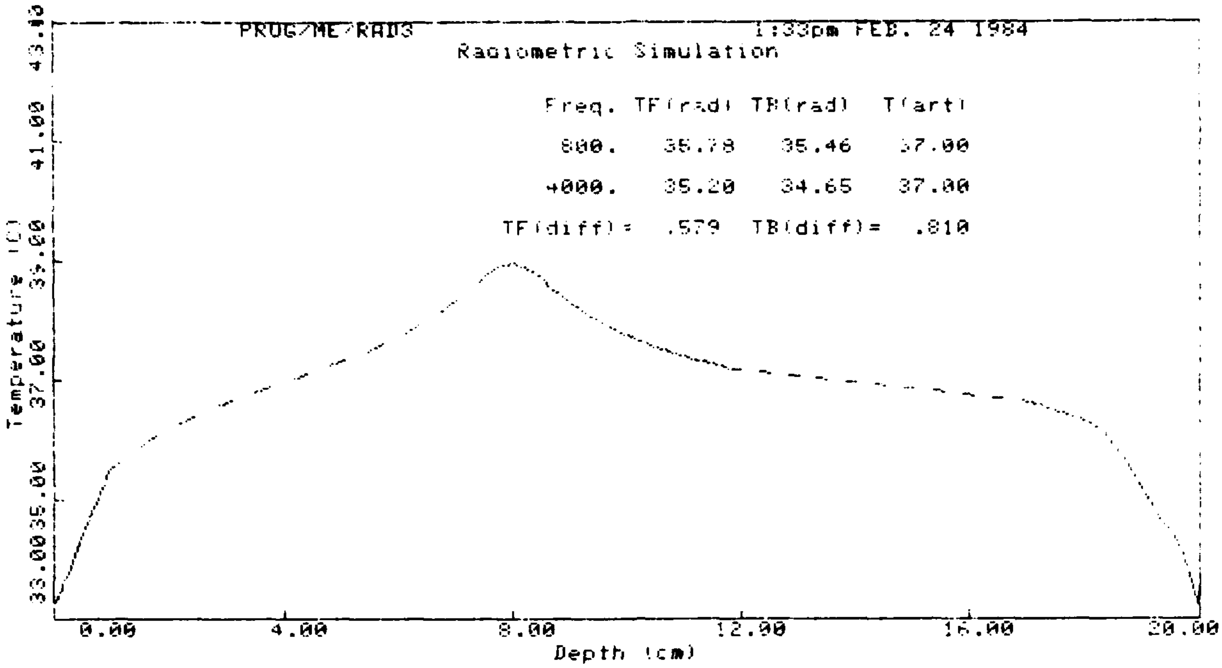

1 Lig. umbilicale medium
2 M. rectus abdominis
3 Intestinum ileum et plica umbilicalis lateralis
4 Lig. umbilicale laterale
5 Intestinum ileum
6 Cavum peritonaei
7 Intestinum ileum
8 Linea semilunaris [Spigeli]
9 Intestinum ileum et m. obliquus internus abdominis
10 Colon ascendens
11 A. et v. ileocolica [rami]
12 Intestinum ileum et valvula coli
13 Processus vermiformis et m. transversus abdominis
14 Spina iliaca anterior superior
15 V. et a. colica dextra
16 A. spermatica interna et v. spermatica
17 N. cutaneus femoris lateralis
18 A. iliaca externa
19 N. femoralis
20 Ureter
21 M. iliopsoas et m. glutaeus minimus
22 V. iliaca externa
23 A. hypogastrica
24 A. iliolumbalis
25 Truncus lumbosacralis
26 M. glutaeus medius
27 V. hypogastrica
28 M. glutaeus maximus
29 Lig. longitudinale anterius
30 Os ilium
31 N. sacralis I
32 A. et v. sacralis lateralis [rami]
33 Foramen sacrale anterius
34 M. multifidus et m. iliocostalis lumborum
35 N. sacralis II
36 Dura mater spinalis
37 Fibrocartilago intervertebralis sacralis I
38 N. sacralis III
39 Canalis sacralis
40 A. et v. haemorrhoidalis superior
41 Lig. sacroiliacum posterius breve
42 Vertebra sacralis I
43 A. et v. sacralis media
44 Crista sacralis lateralis
45 Cavum peritonaei
46 M. glutaeus maximus
47 Cavum peritonaei
48 V. hypogastrica
49 Truncus lumbosacralis
50 A. et v. iliolumbalis
51 N. obturatorius
52 V. iliaca externa
53 A. hypogastrica
54 Ureter
55 N. femoralis
56 N. cutaneus femoris lateralis
57 A. iliaca externa
58 A. et v. sigmoidea [rami]
59 Tendo m. tensoris fasciae latae et n. lumboinguinalis
60 A. et v. circumflexa ilium profunda
61 A. spermatica interna et v. spermatica et n. spermaticus externus
62 Colon descendens
63 Omentum majus
64 M. transversus abdominis
65 Intestinum ileum
66 Fascia transversalis
67 Mesenterium
68 Intestinum ileum
69 A. et v. epigastrica inferior
70 Intestinum ileum
71 Lig. umbilicale laterale
72 Intestinum ileum

SECTION 38

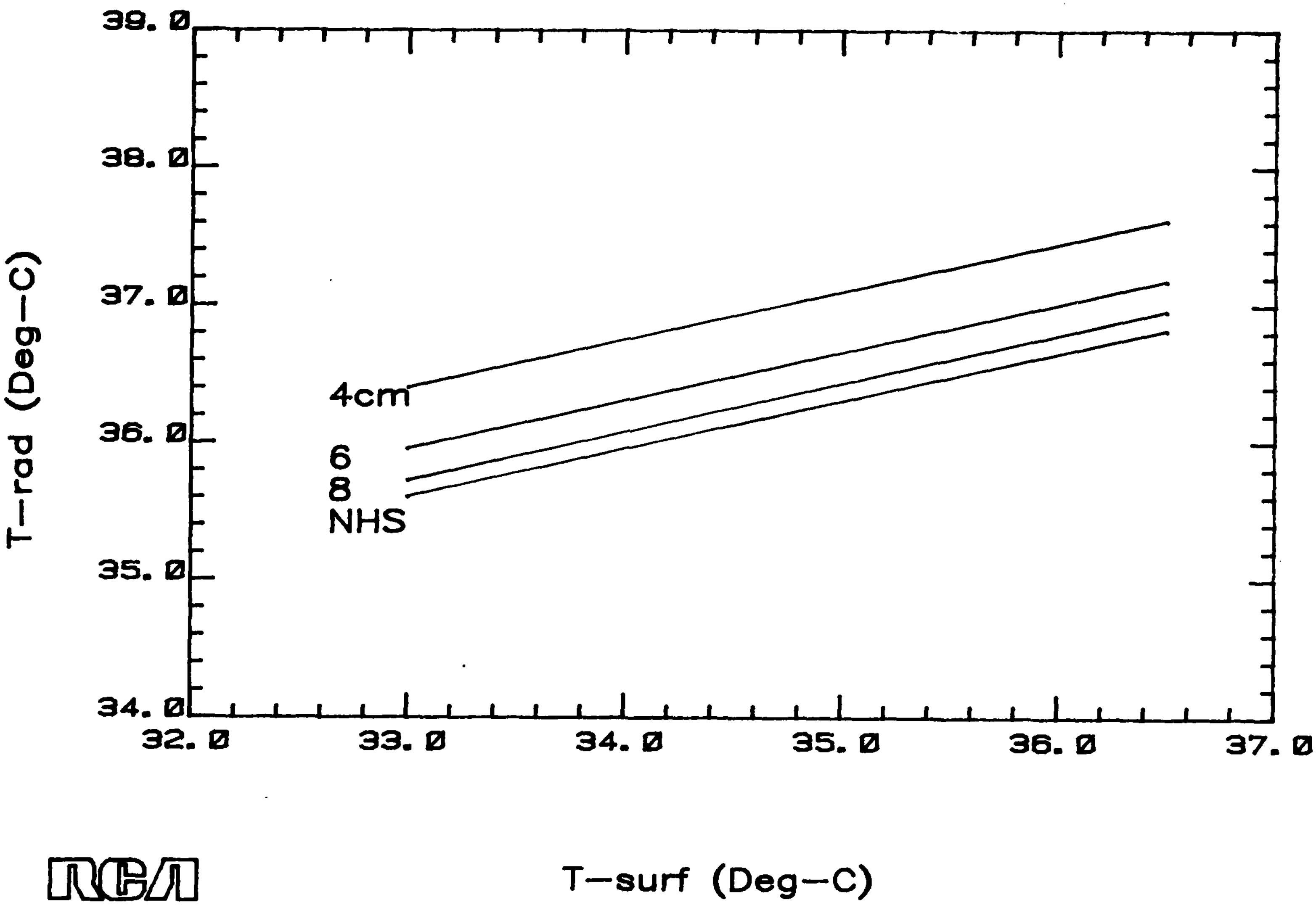


PROG/ME/RAD3
1:39pm FEB. 24 1984
Radiometric Simulation
Freq. TF(rad) TB(rad) T(art)
800. 36.61 35.33 37.00
4000. 35.89 34.60 37.00
TF(diff)= .720 TB(diff)= .735
Temperature (C)
Depth (cm)

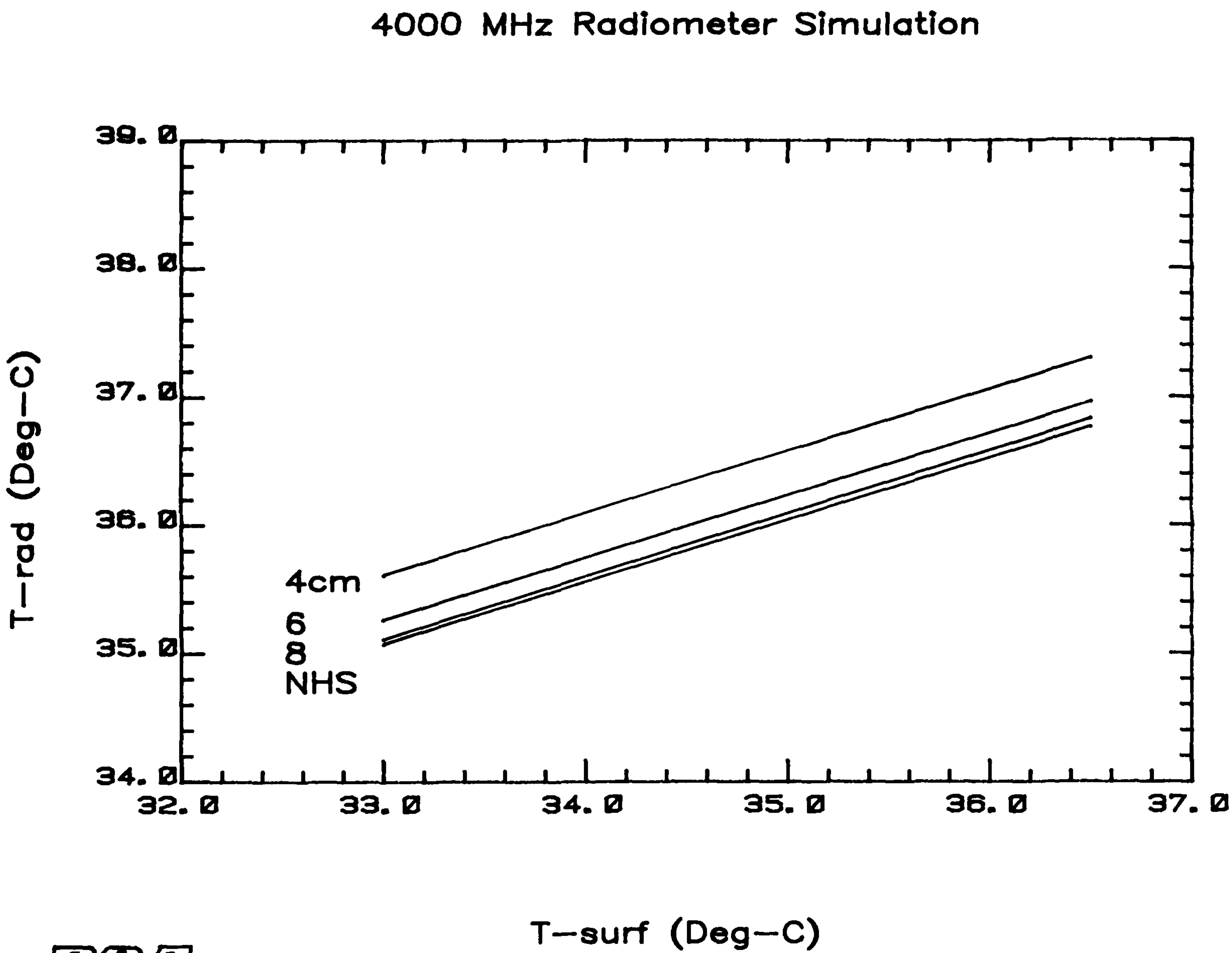

PROG/ME/RAD3
1:36pm FEB. 24 1984
Radiometric Simulation
Freq. TF(rad) TB(rad) T(art)
800. 36.05 35.37 37.00
4000. 35.40 34.61 37.00
TF(diff)= .649 TB(diff)= .757
Temperature (C)
33.00
35.00
37.00
39.00
41.00
43.00
0.00
4.00
8.00
12.00
16.00
20.00
Depth (cm)

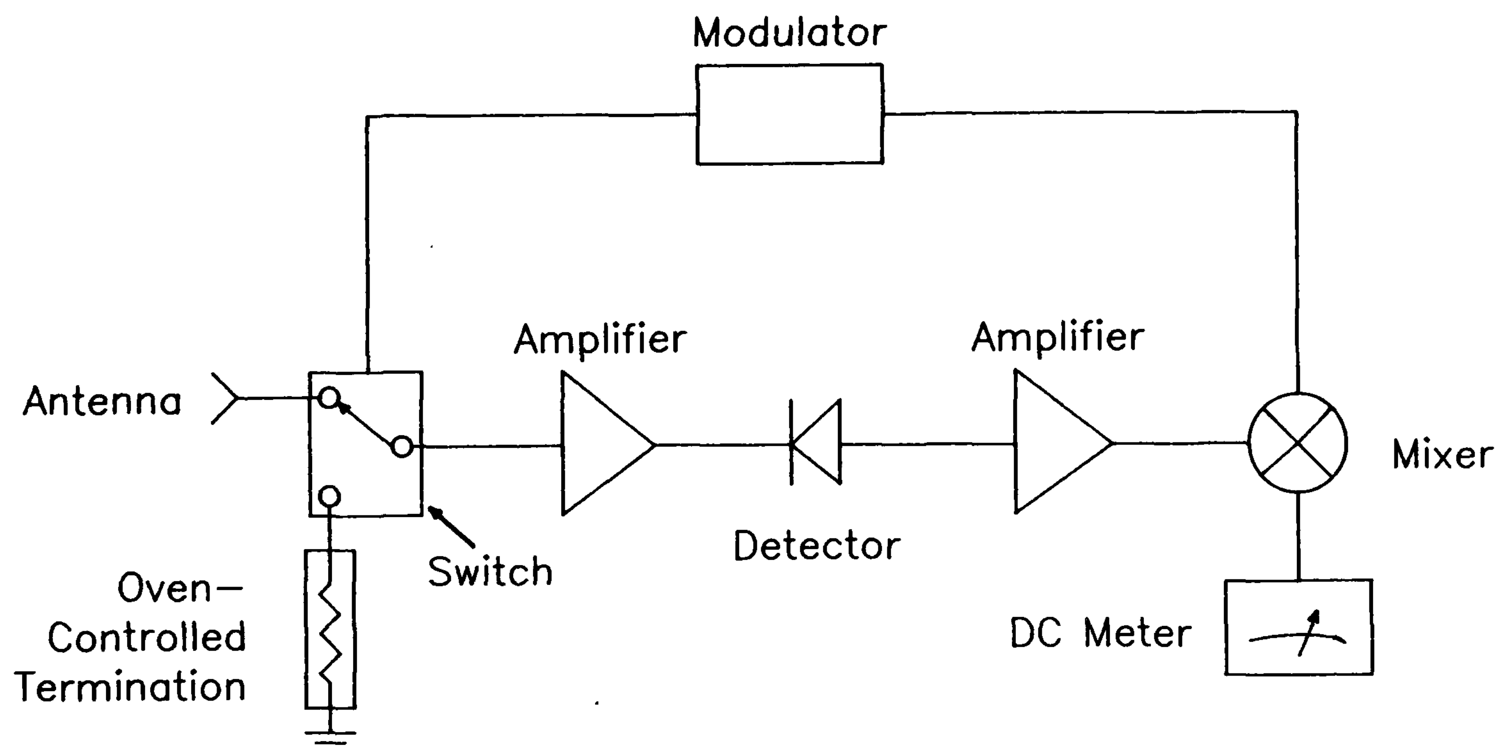

PROG/ME/RAD3
1:33pm FEB. 24 1984
Radiometric Simulation
Freq. TF(rad) TB(rad) T(art)
800. 35.78 35.46 37.00
4000. 35.20 34.65 37.00
TF(diff)= .579 TB(diff)= .810
Temperature (C)
33.00
35.00
37.00
39.00
41.00
43.00
0.00
4.00
8.00
12.00
16.00
20.00
Depth (cm)

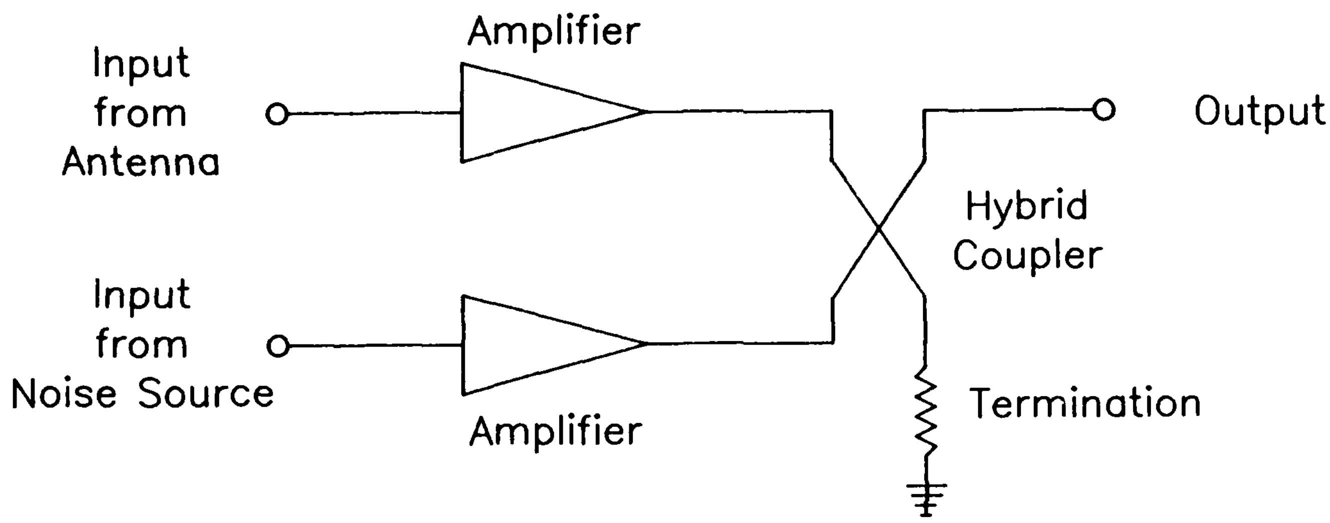
800 MHz Radiometer Simulation

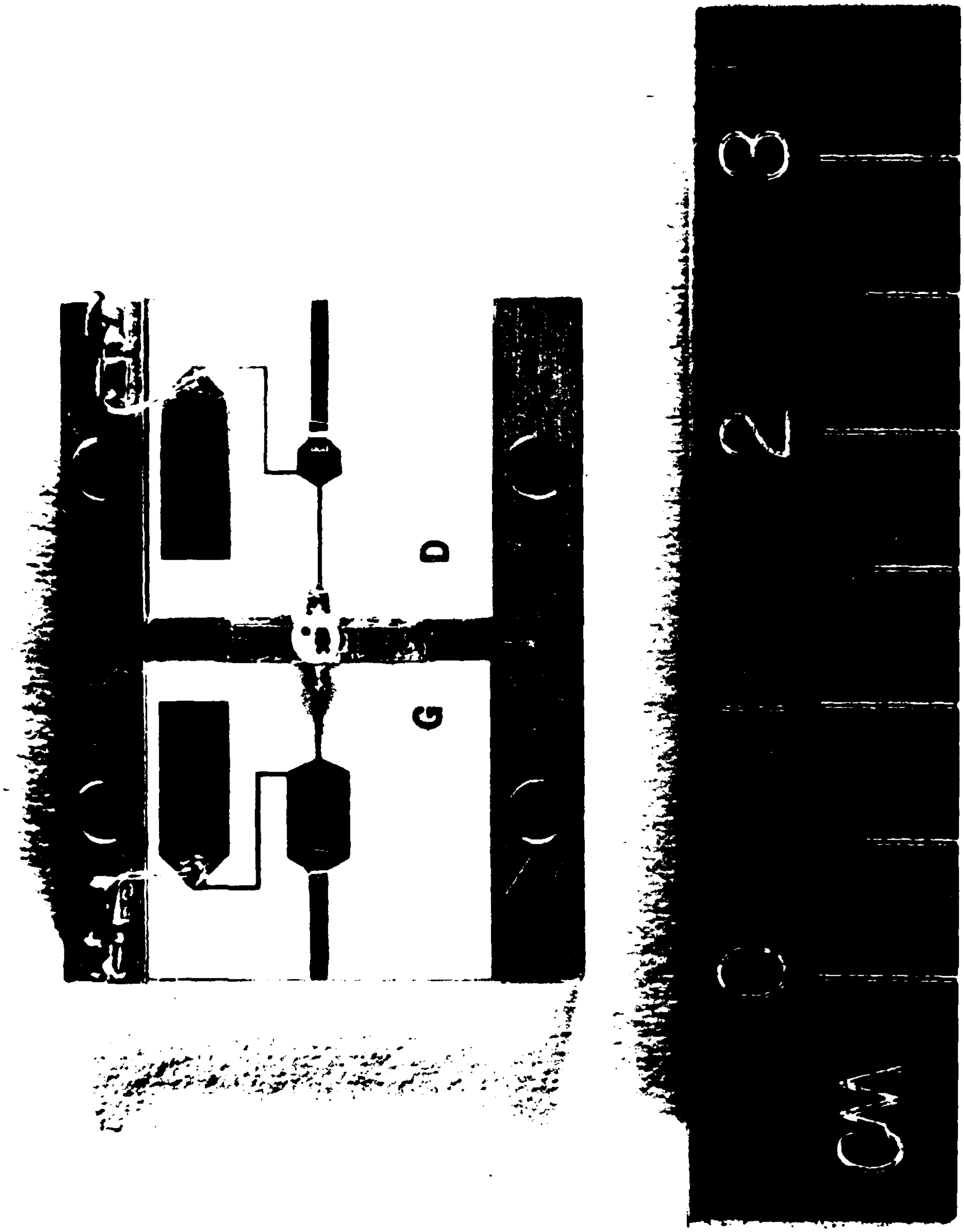



RCA

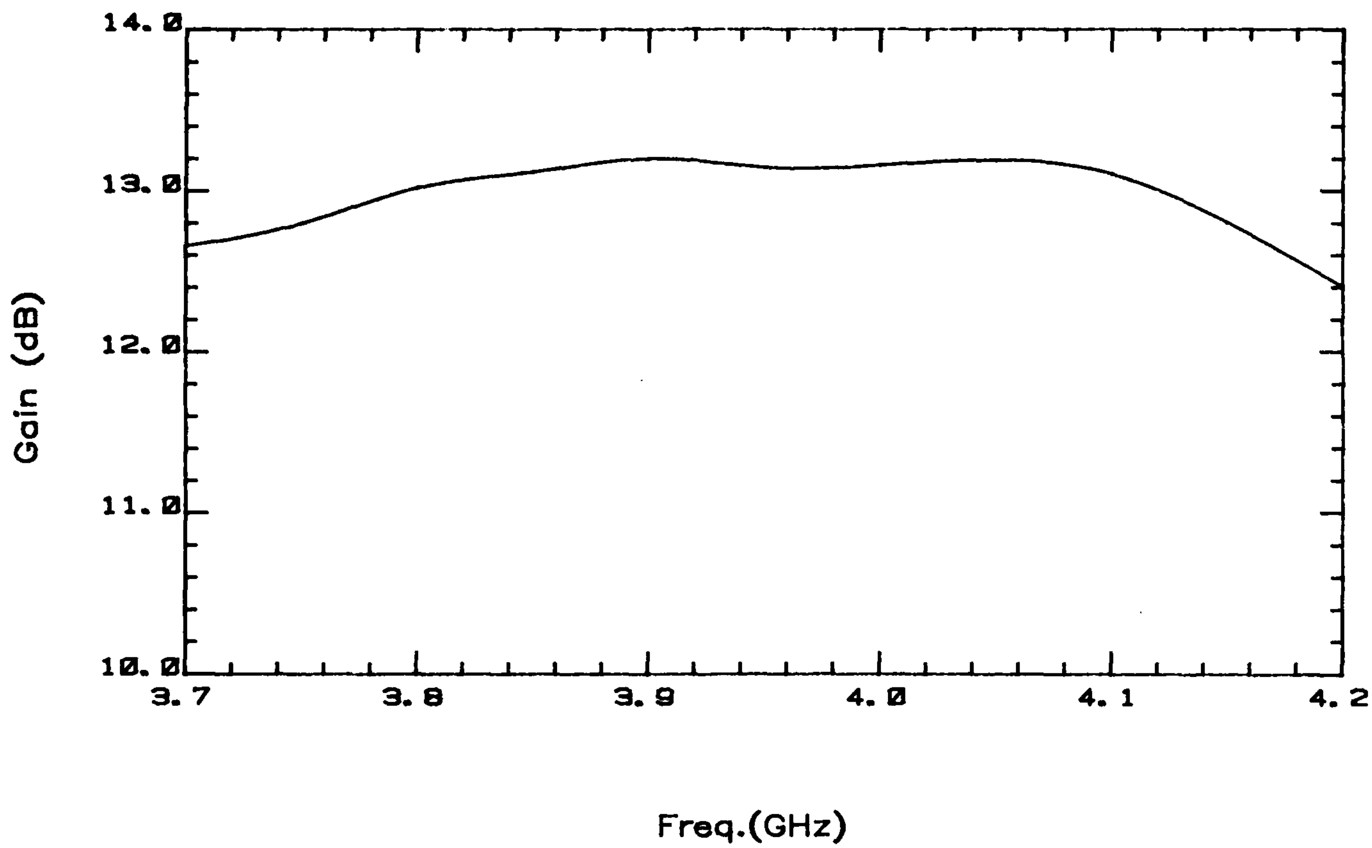

4000 MHz Radiometer Simulation
T-rad (Deg-C)
39.0
38.0
37.0
36.0
35.0
34.0
32.0
33.0
34.0
35.0
36.0
37.0
4cm
6
8
NHS
T-surf (Deg-C)

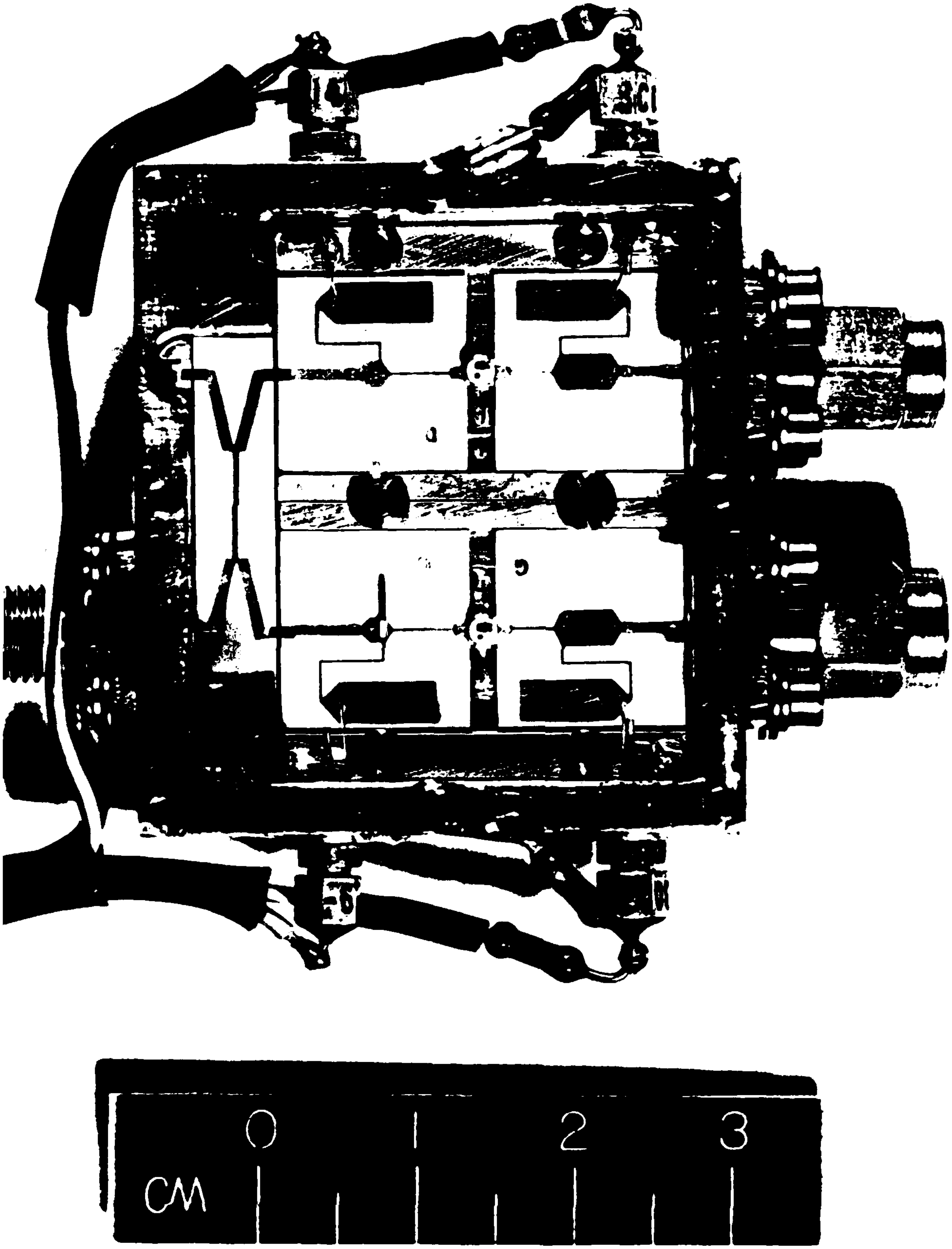

Modulator
Amplifier
Amplifier
Antenna
Mixer
Detector
Switch
Oven-
Controlled
Termination
DC Meter

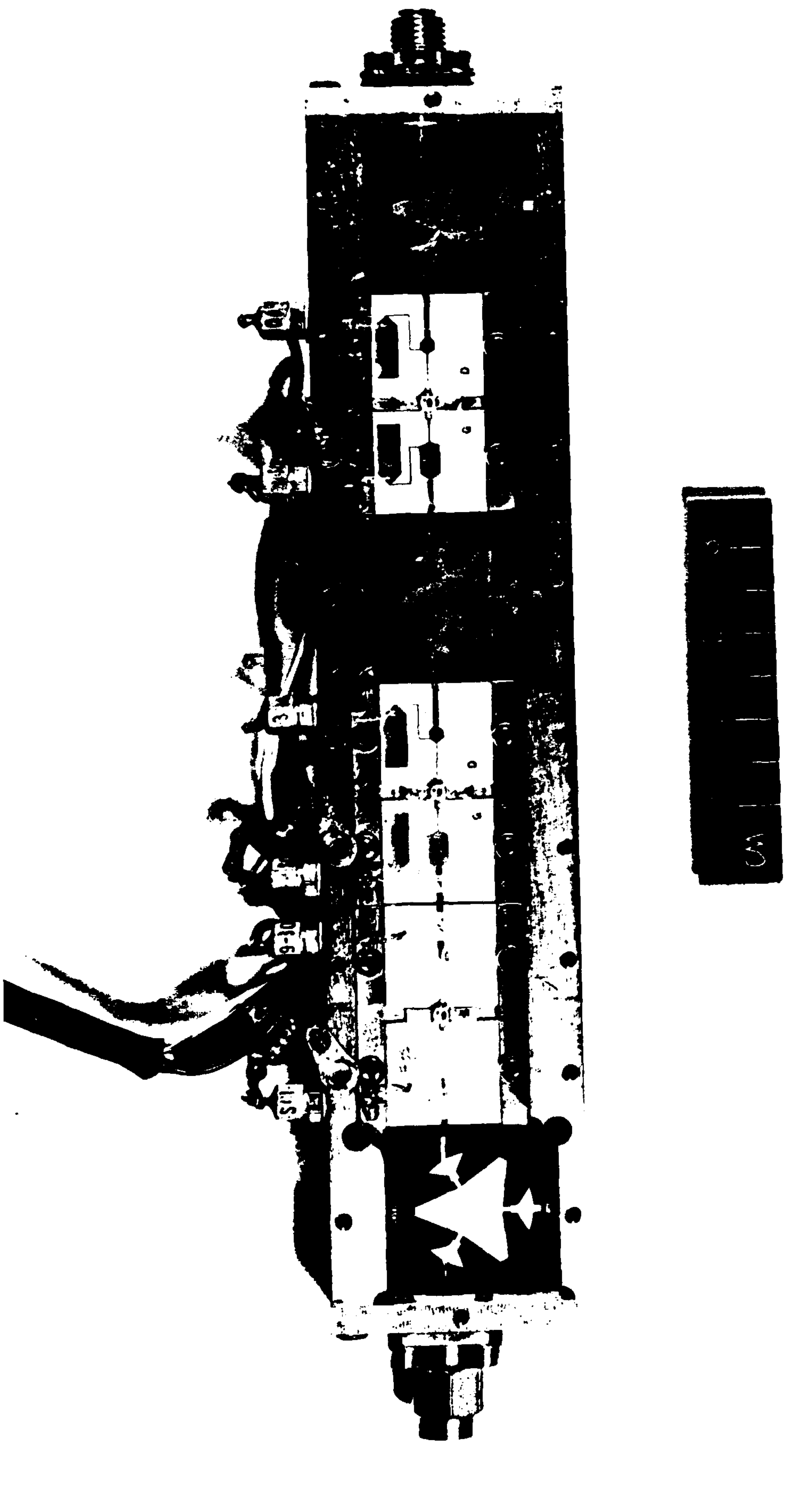

Amplifier
Input
from
Antenna
Output
Hybrid
Coupler
Input
from
Noise Source
Termination
Amplifier

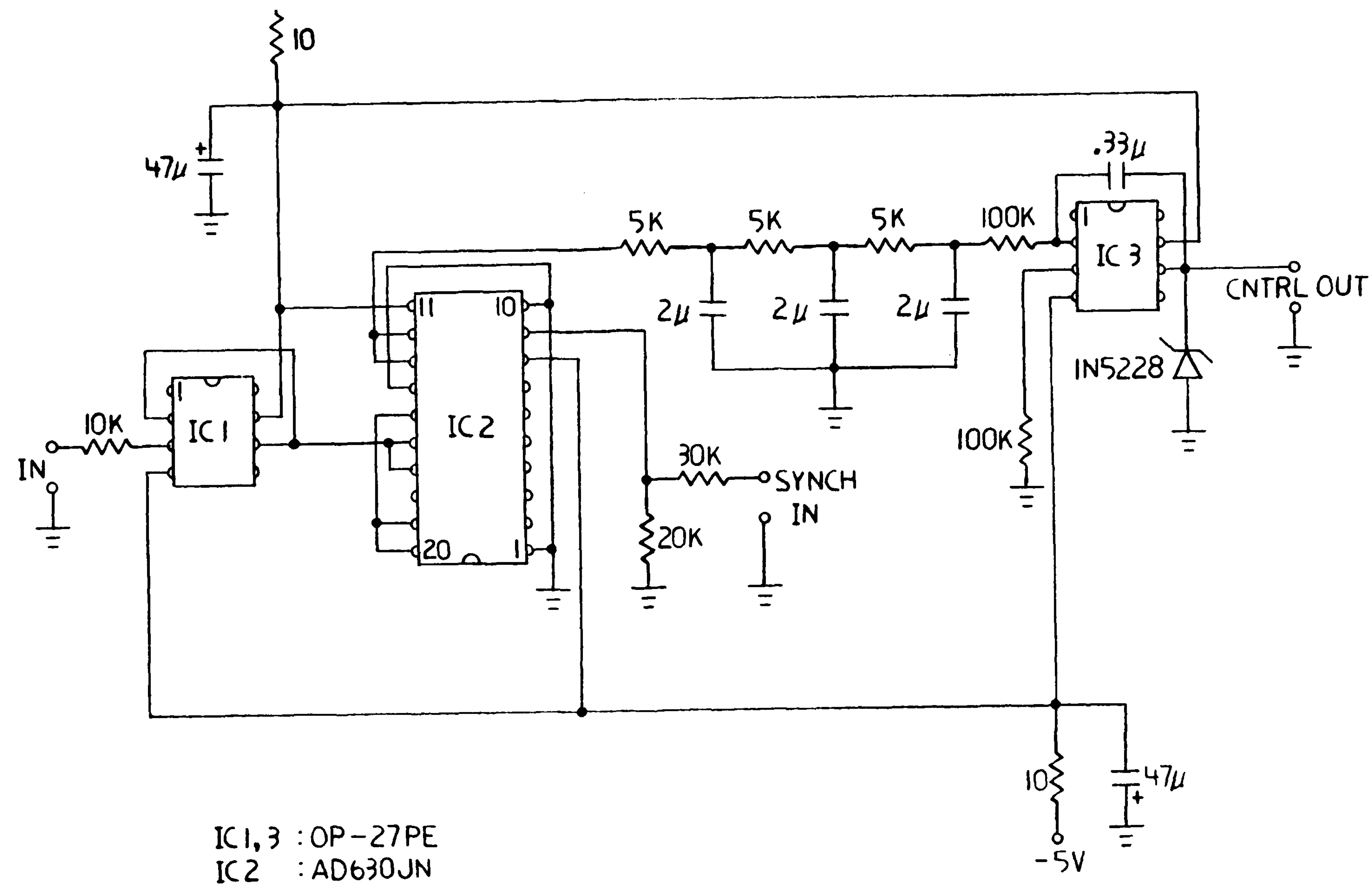


D
G
CM
2
3

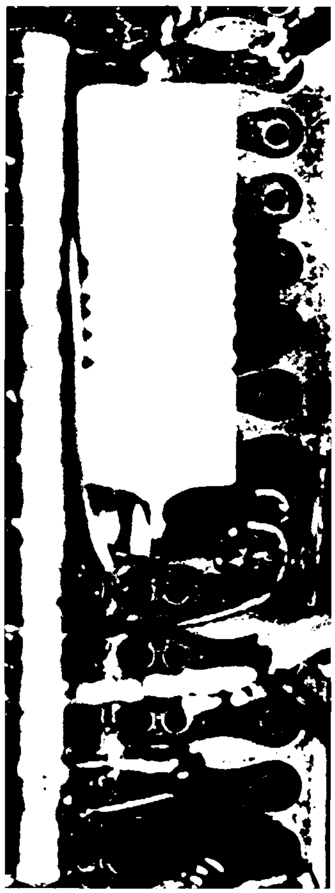

14.0
13.0
12.0
11.0
10.0
Gain (dB)
3.7
3.8
3.9
4.0
4.1
4.2
Freq.(GHz)

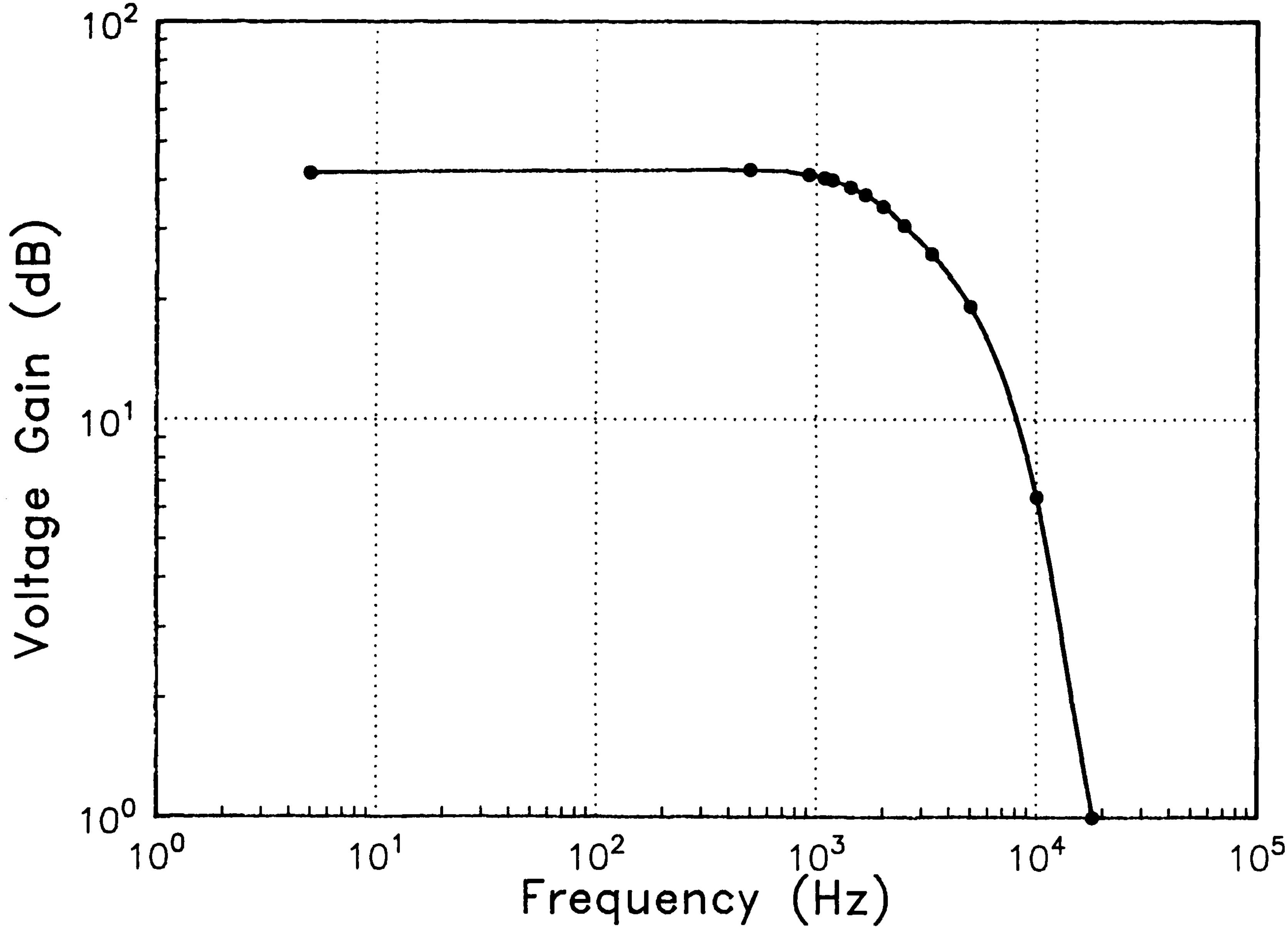

0 1 2 3
CM



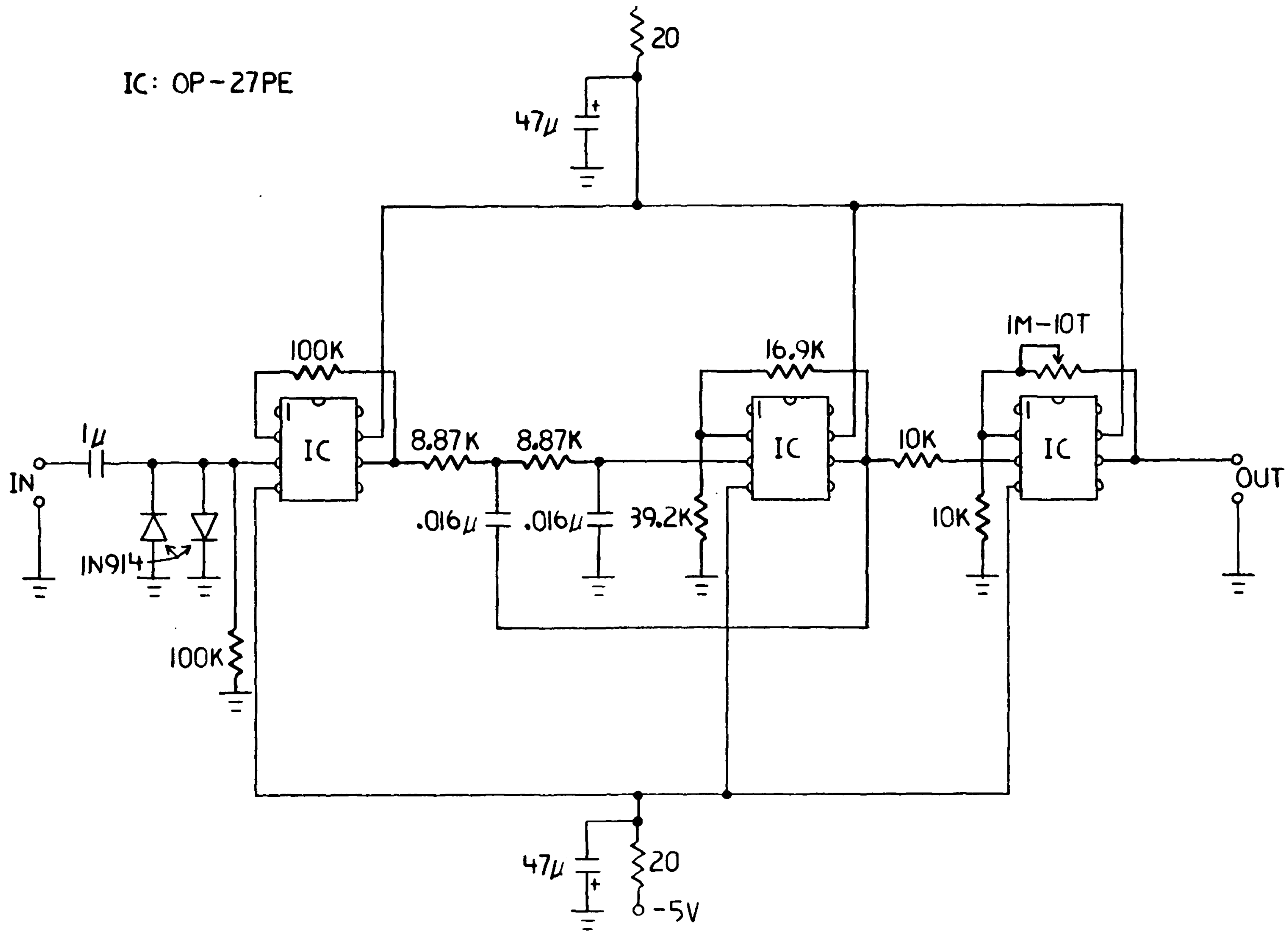



IC1, 3 : OP-27PE
IC2 : AD630JN

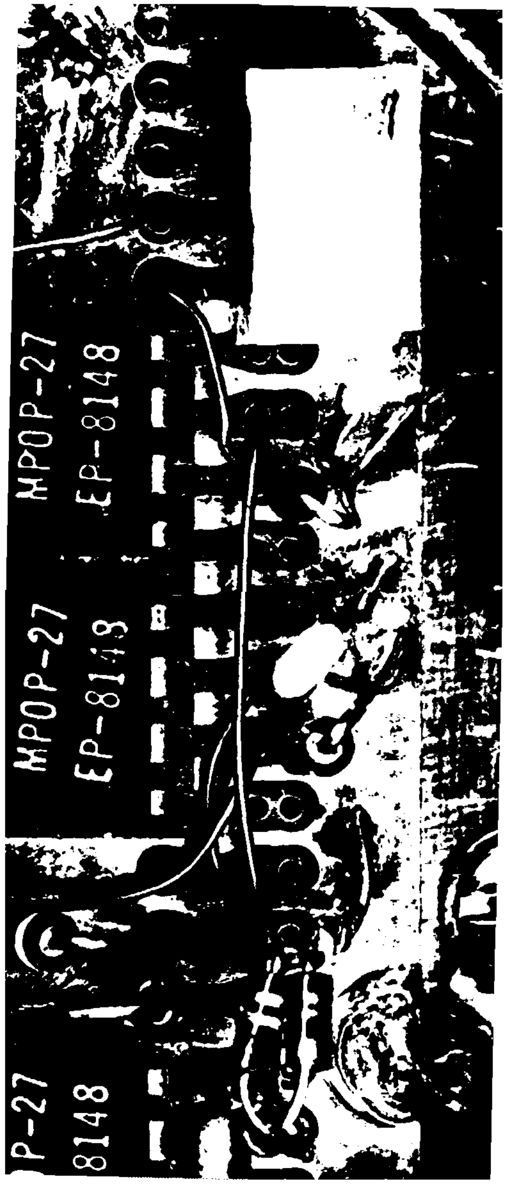


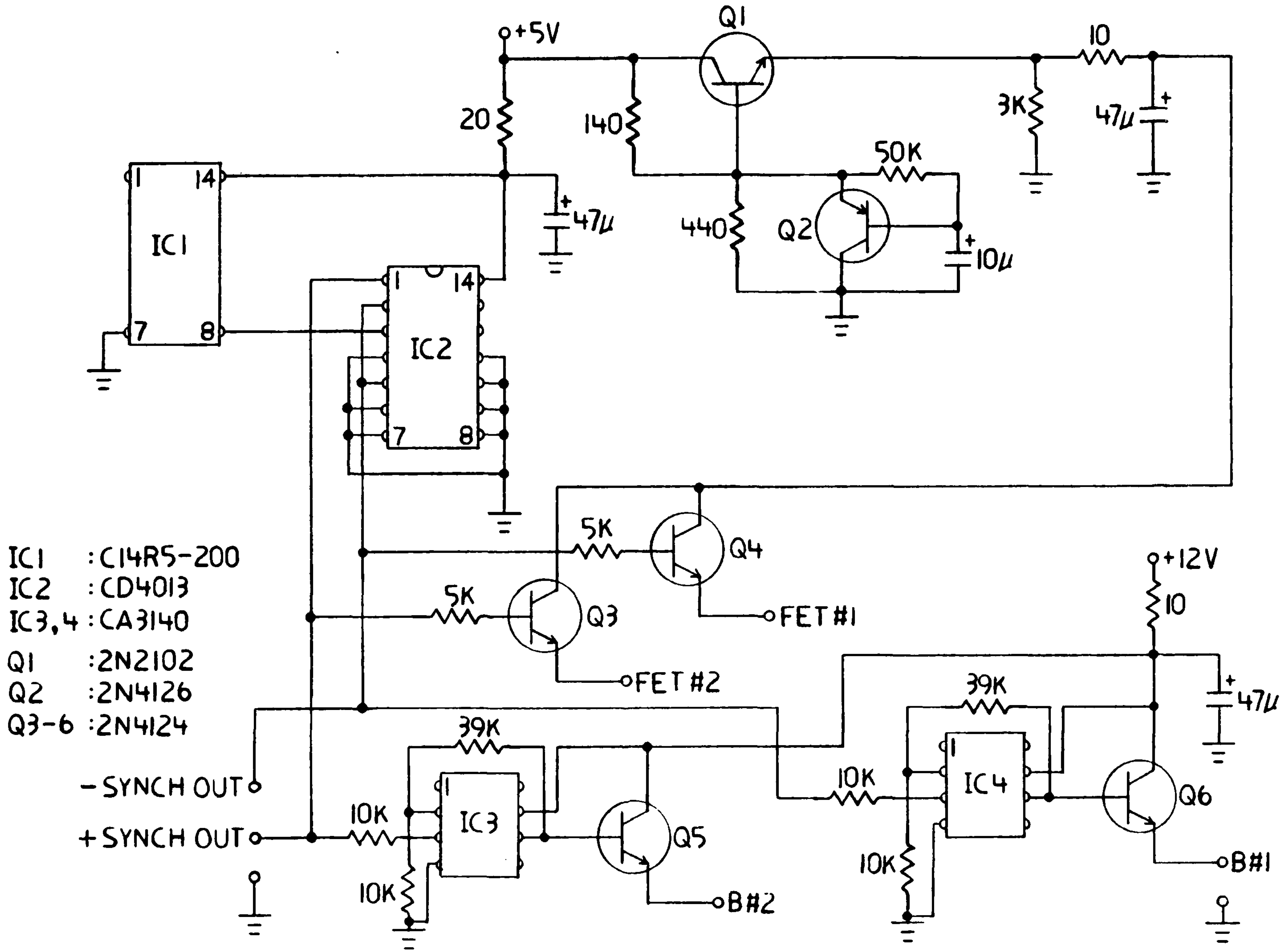


Voltage Gain (dB)
10^2
10^1
10^0
10^0
10^1
10^2
10^3
10^4
10^5
Frequency (Hz)

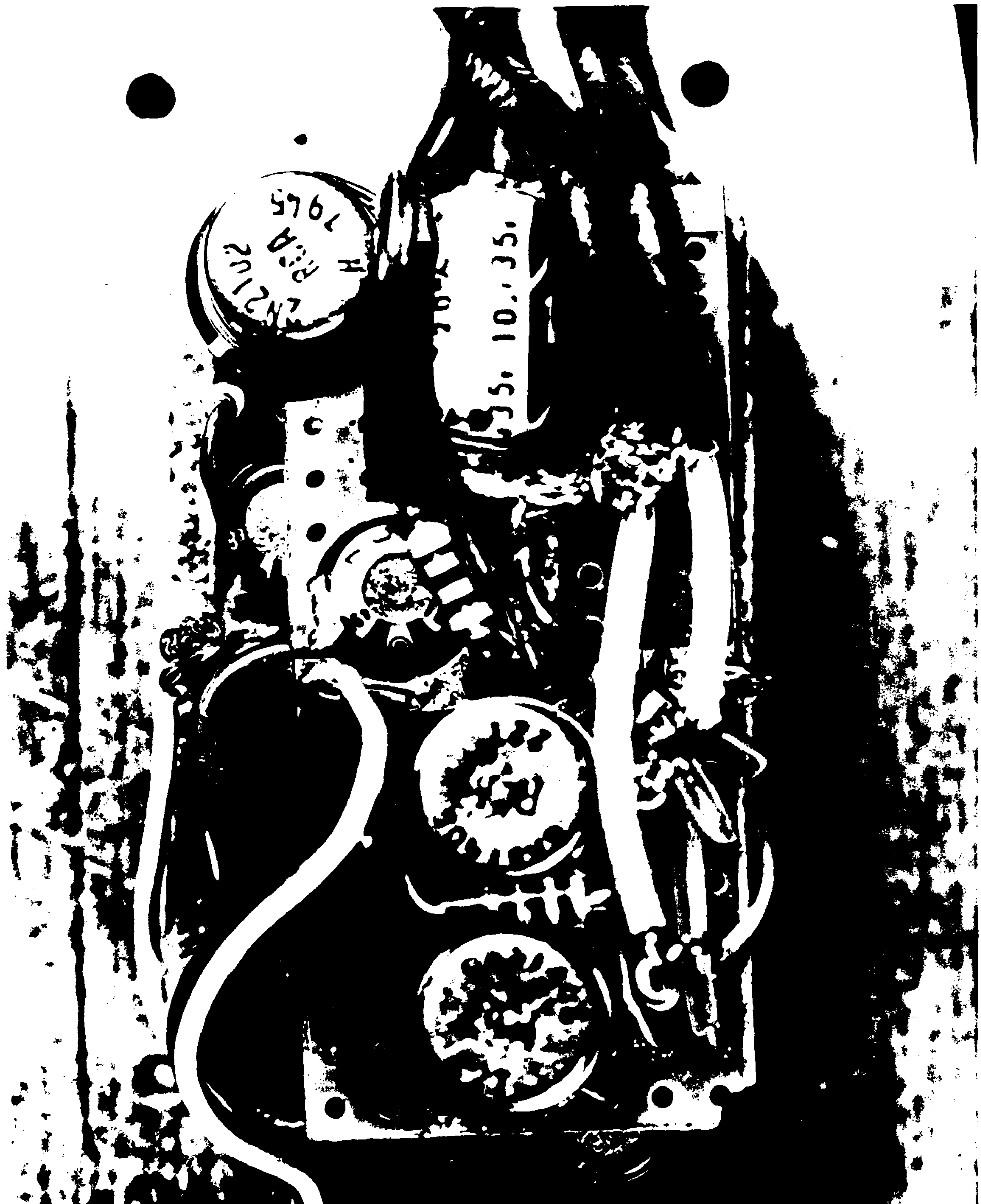


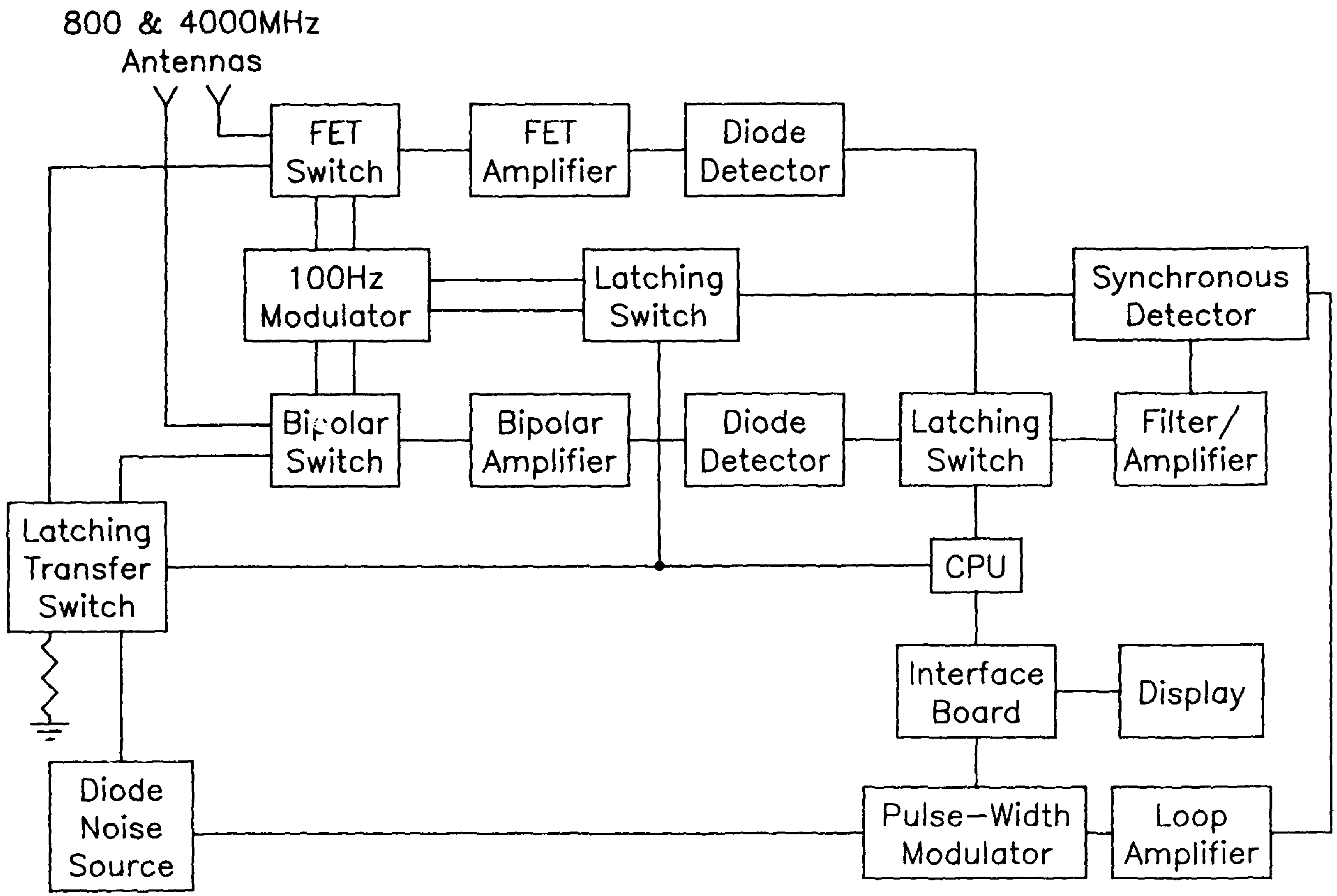
IC: OP-27PE
20
47μ
100K
16.9K
1M-10T
1μ
IN
IC
8.87K
8.87K
IC
10K
IC
OUT
1N914
.016μ
.016μ
39.2K
10K
100K
47μ
20
-5V


MPOP-27
EP-8148
MPOP-27
EP-8148

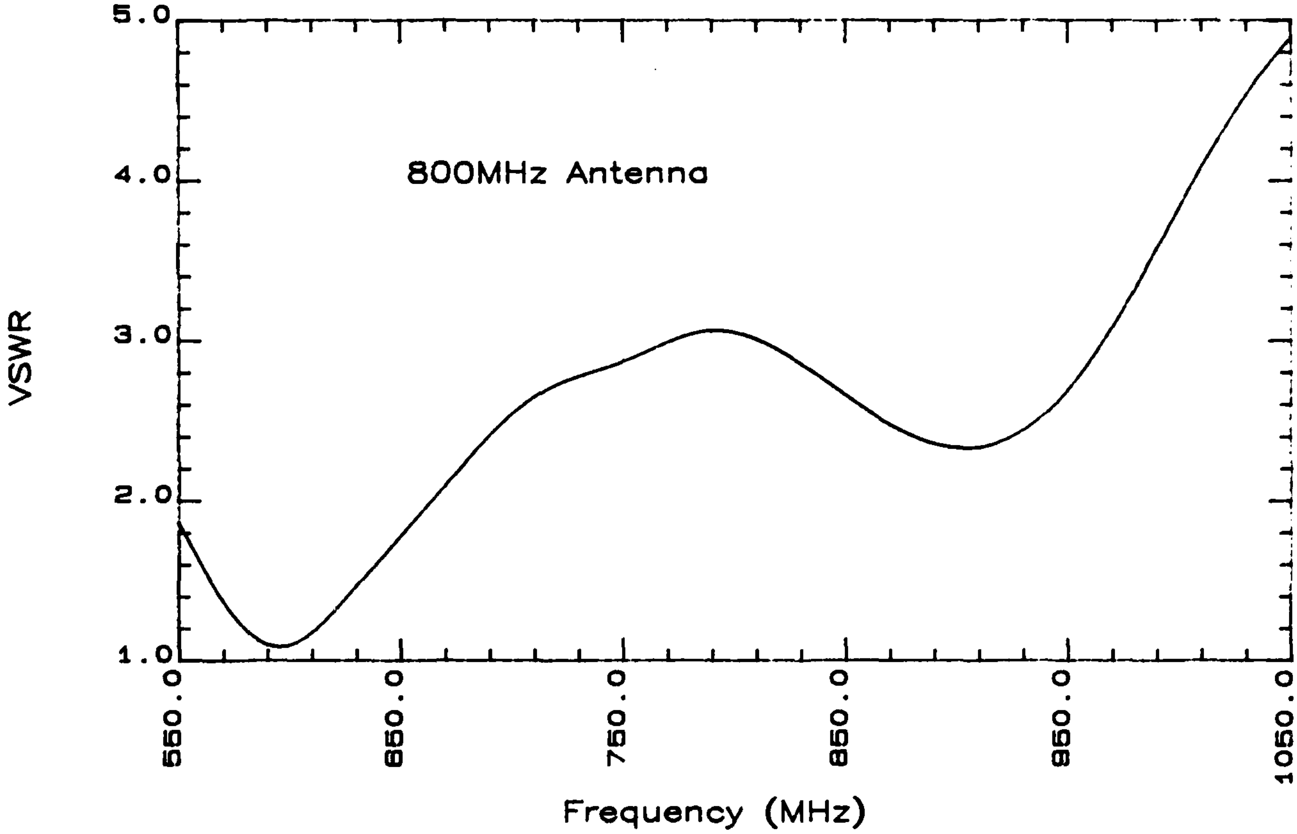


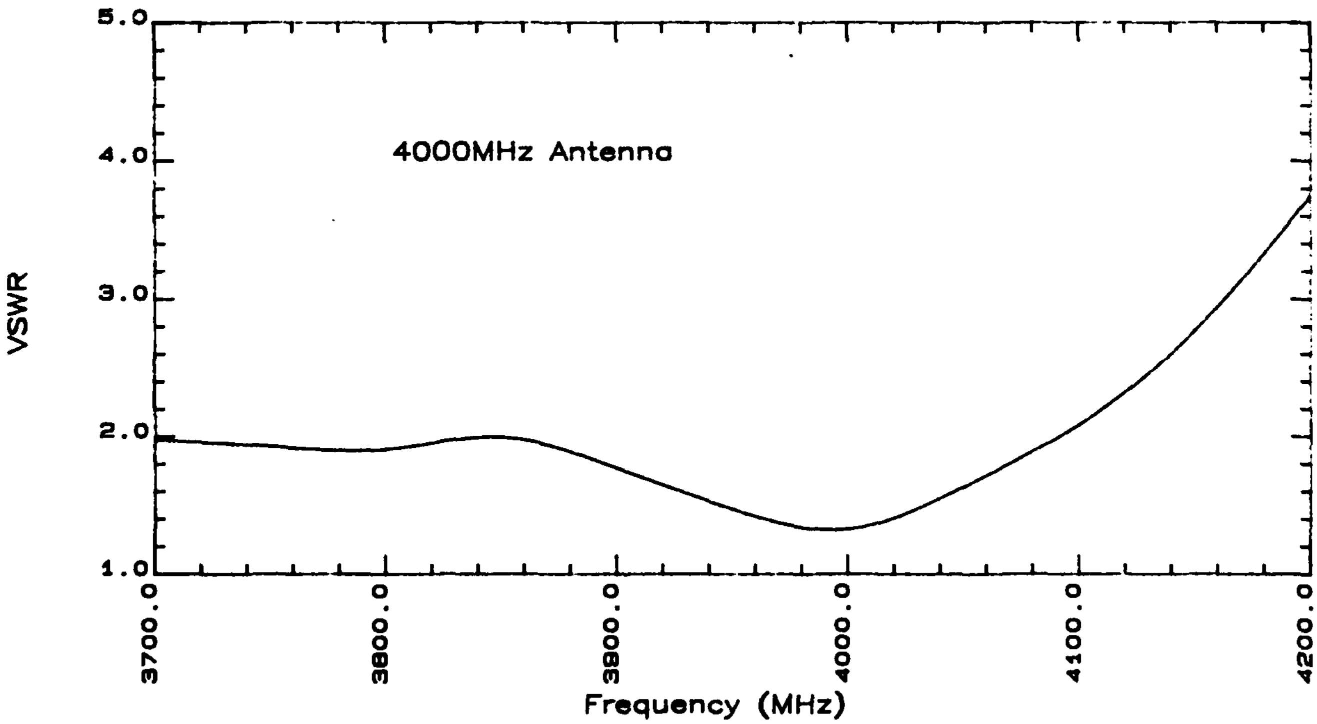
+5V
Q1
10
3K
47µ
20
140
50K
440
Q2
10µ
IC1
1
14
7
8
IC2
1
14
7
8
5K
Q4
5K
Q3
FET #1
FET #2
+12V
10
39K
39K
10K
10K
10K
10K
IC3
1
IC4
1
Q5
Q6
B#1
B#2
−SYNCH OUT
+SYNCH OUT
IC1 : C14R5-200
IC2 : CD4013
IC3,4 : CA3140
Q1 : 2N2102
Q2 : 2N4126
Q3-6 : 2N4124

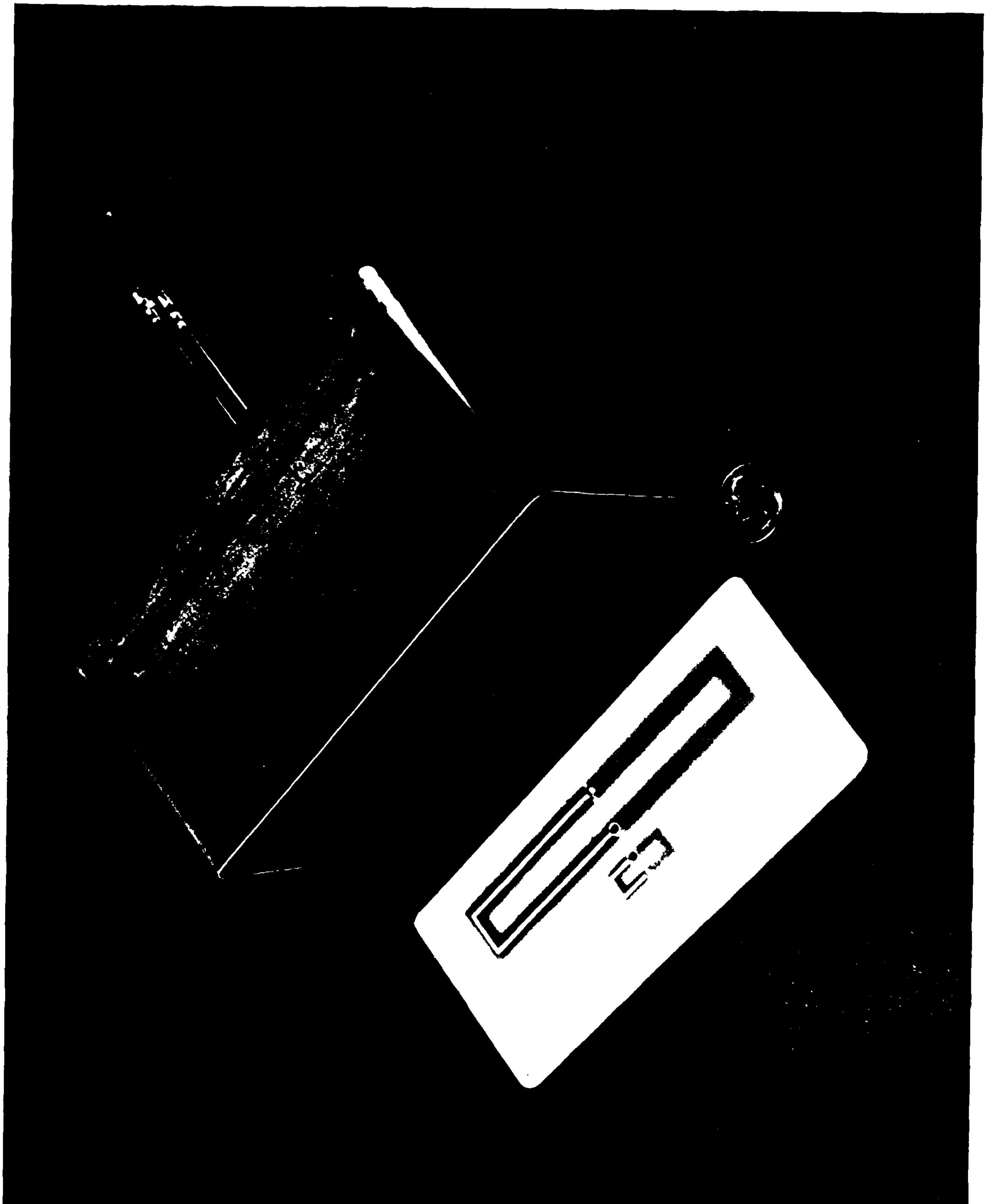


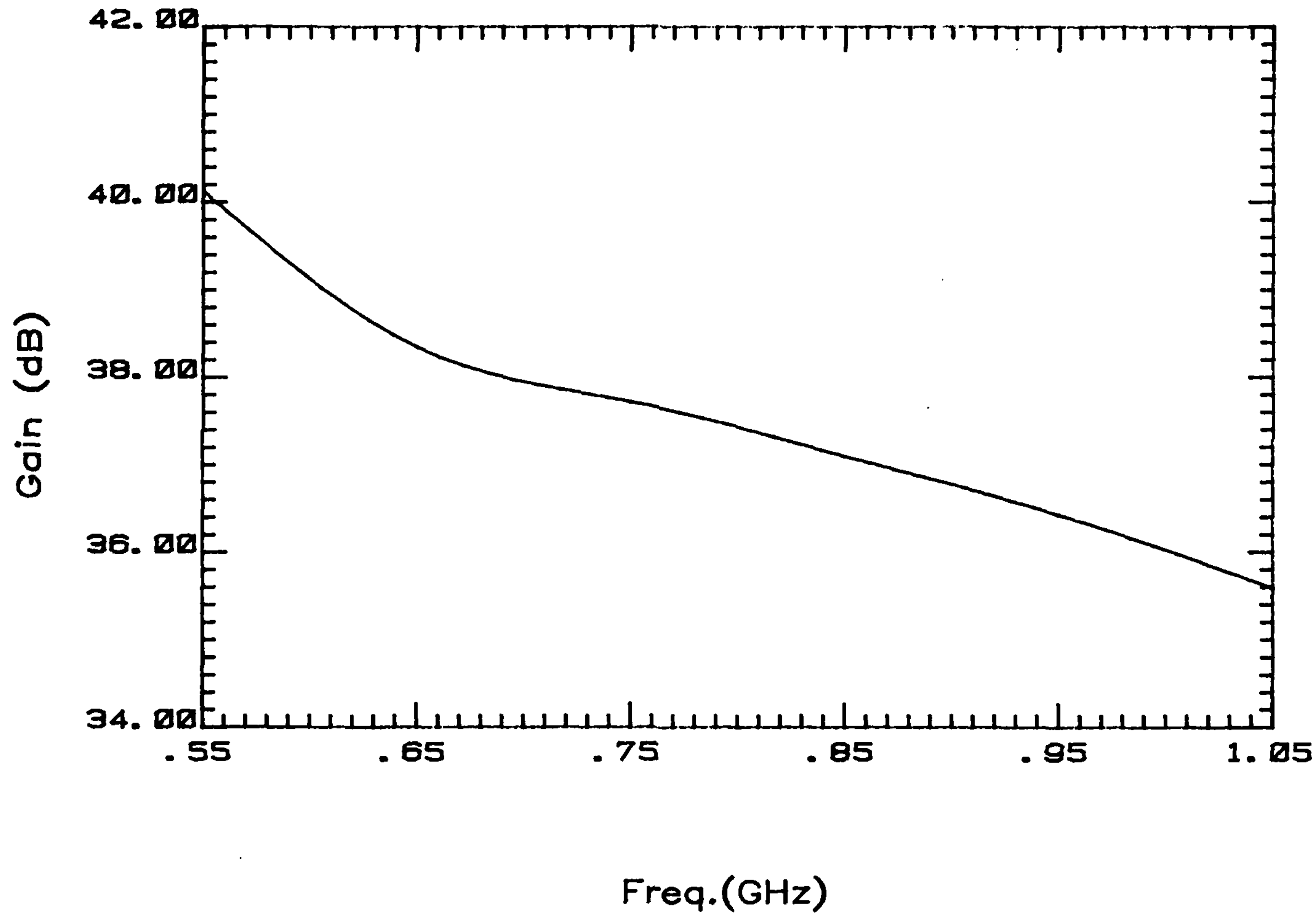


800 & 4000MHz
Antennas
FET Switch
FET Amplifier
Diode Detector
100Hz Modulator
Latching Switch
Synchronous Detector
Bipolar Switch
Bipolar Amplifier
Diode Detector
Latching Switch
Filter/ Amplifier
Latching Transfer Switch
CPU
Interface Board
Display
Diode Noise Source
Pulse-Width Modulator
Loop Amplifier

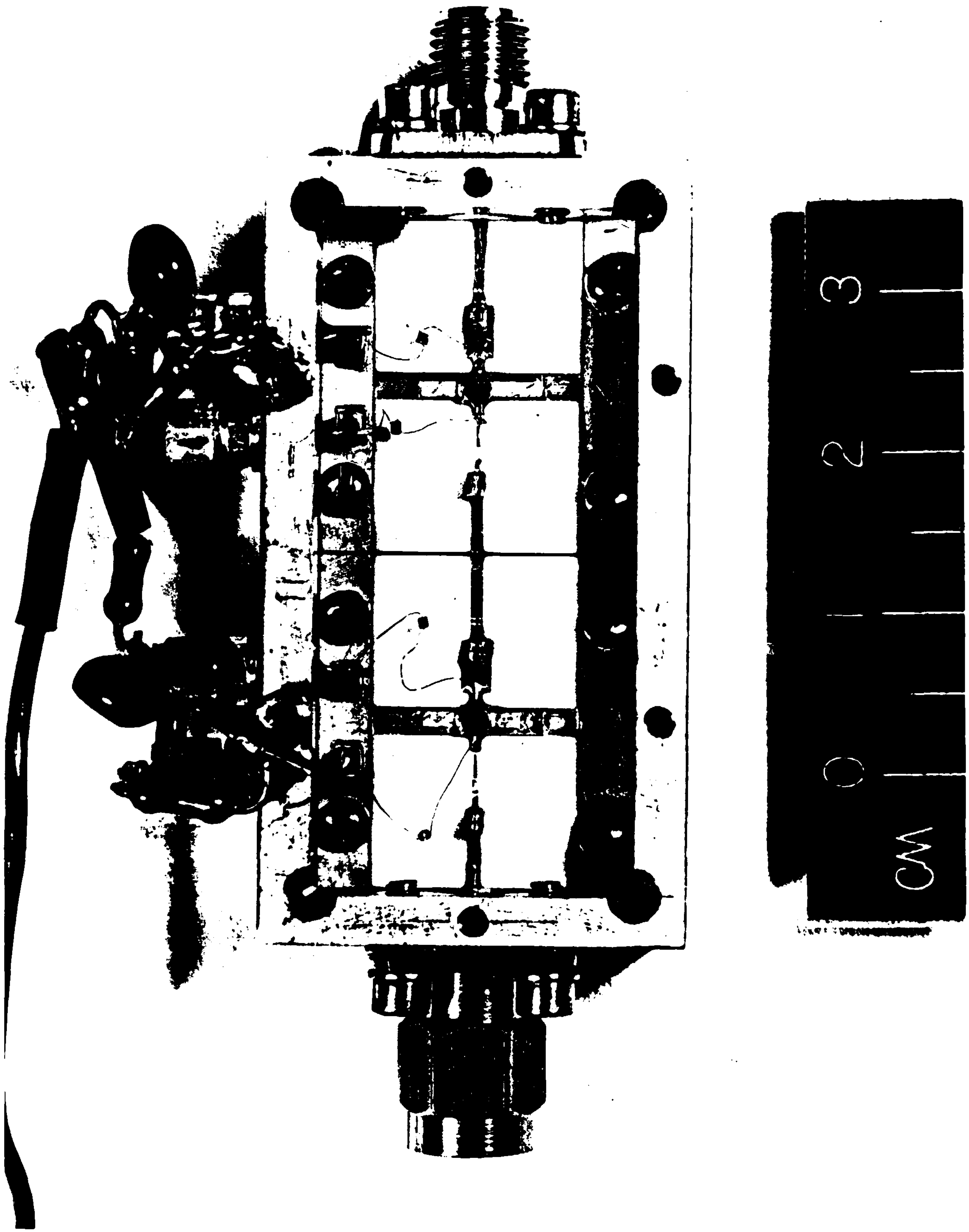

800MHz Antenna
VSWR
5.0
4.0
3.0
2.0
1.0
550.0
650.0
750.0
850.0
950.0
1050.0
Frequency (MHz)

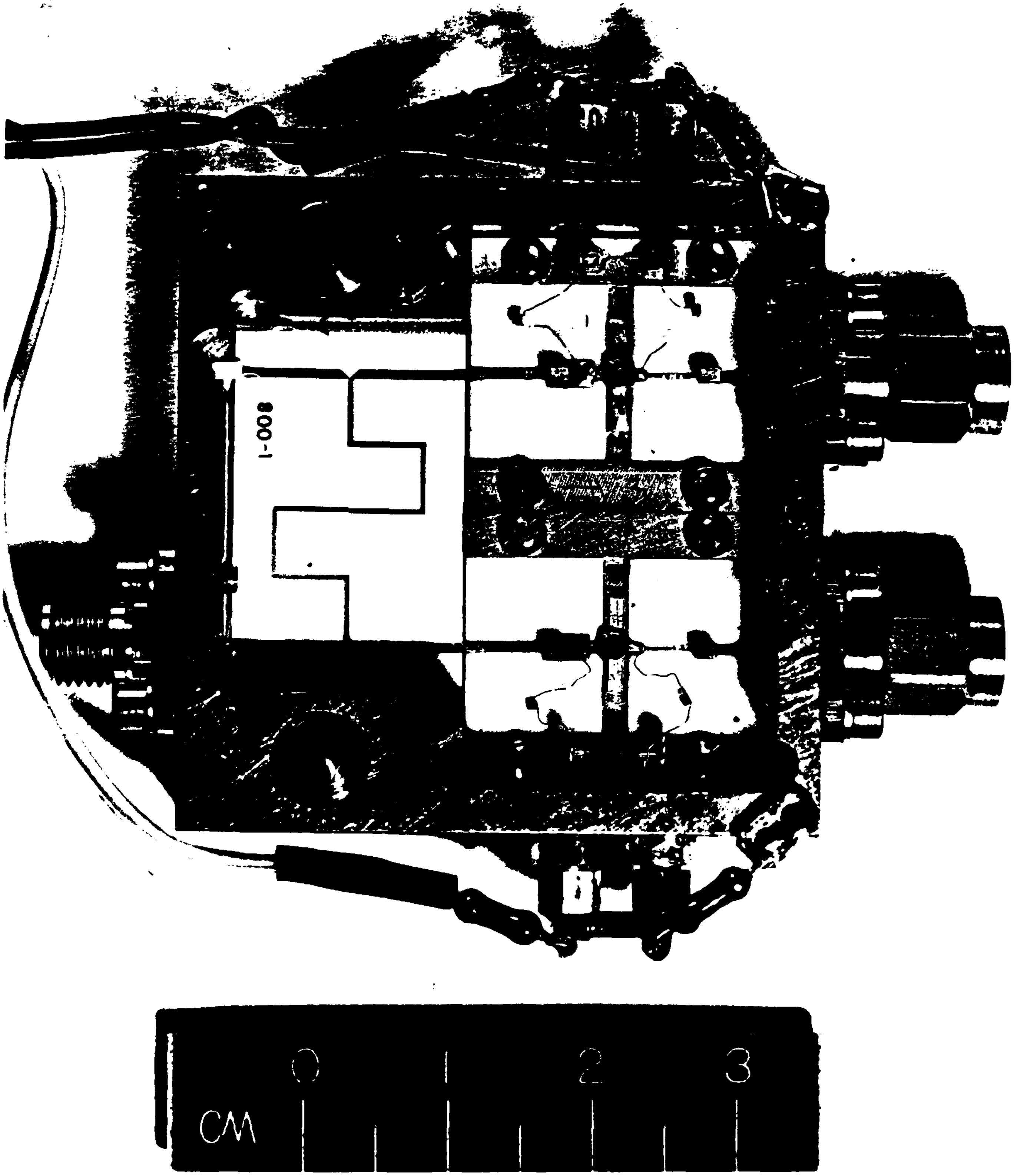

4000MHz Antenna
VSWR
5.0
4.0
3.0
2.0
1.0
3700.0
3800.0
3900.0
4000.0
4100.0
4200.0
Frequency (MHz)

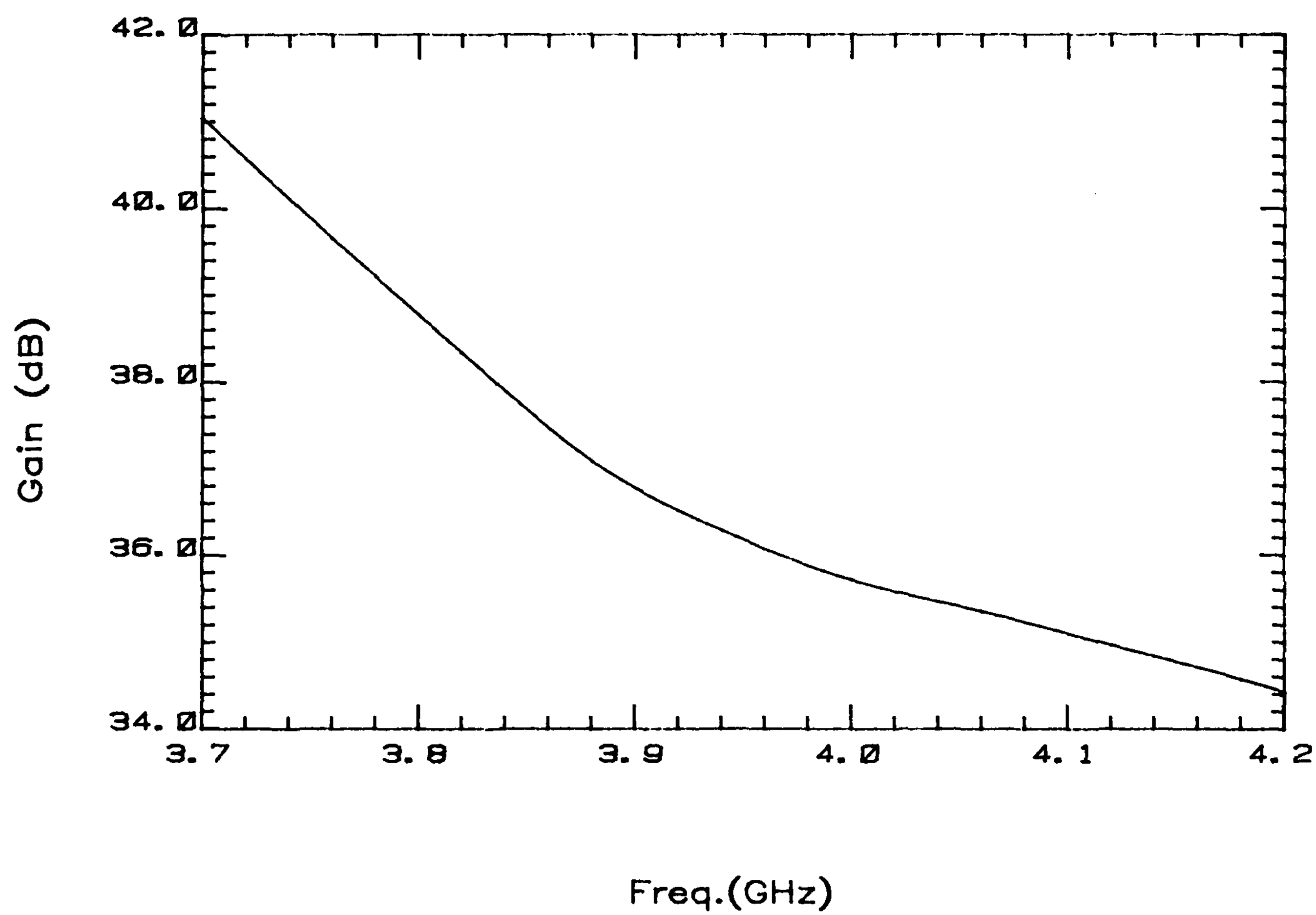


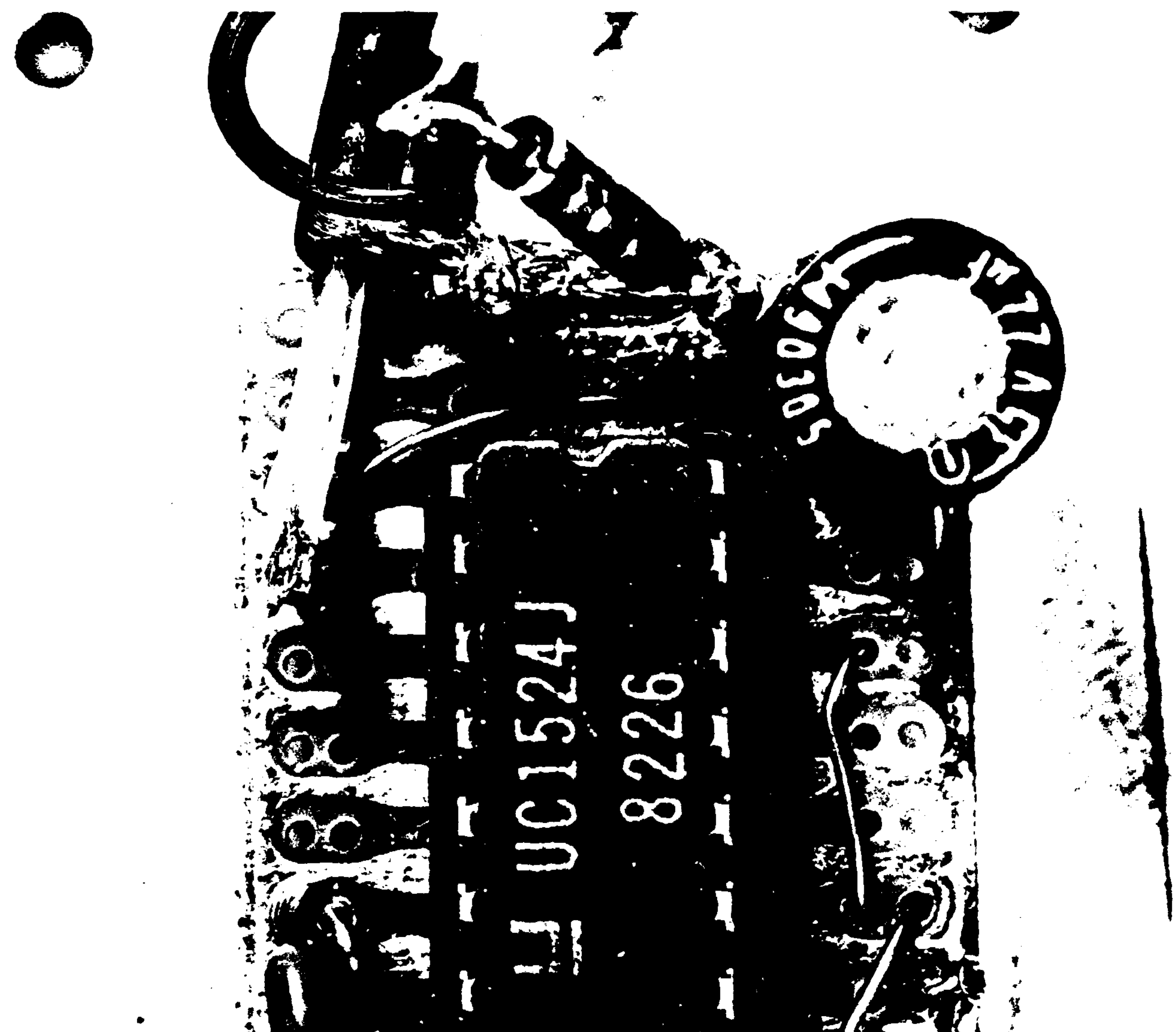


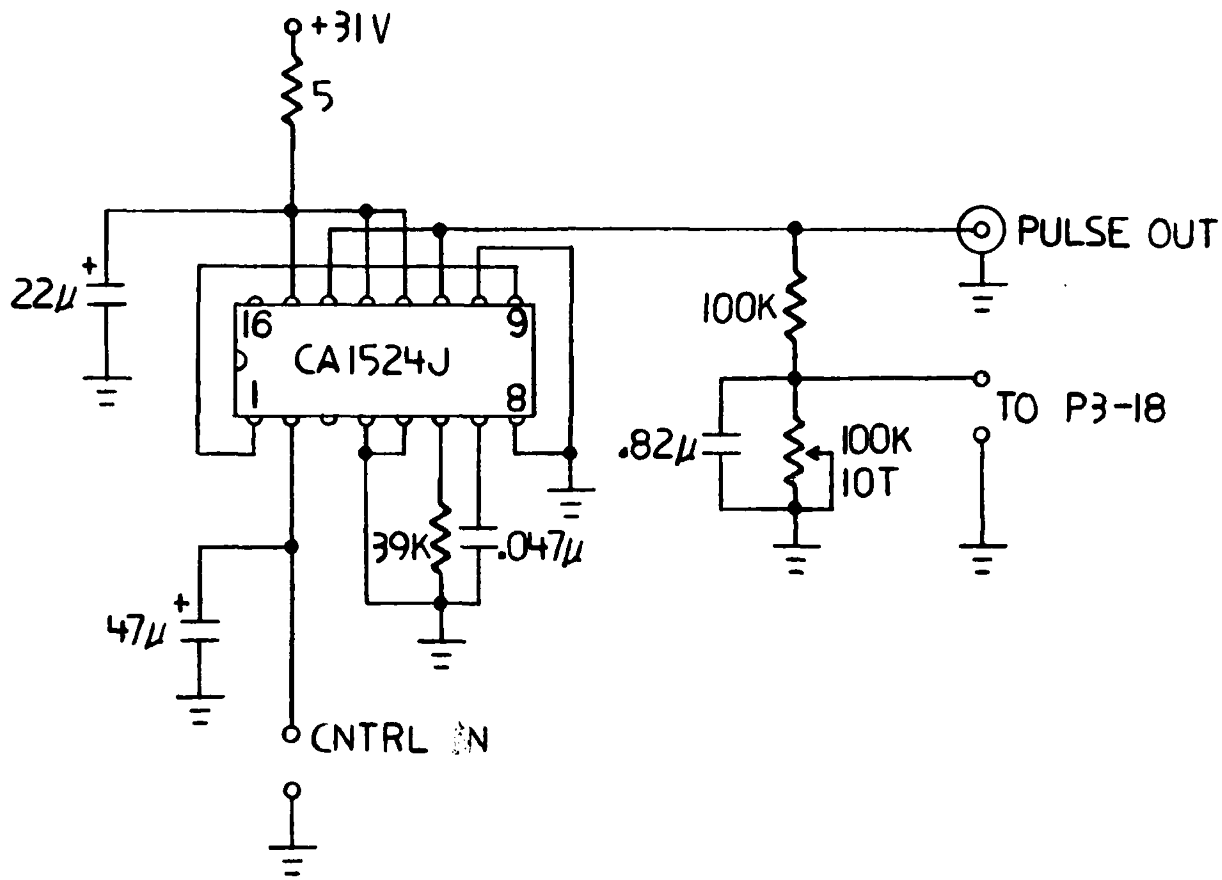
42.00
40.00
38.00
36.00
34.00
Gain (dB)
.55
.65
.75
.85
.95
1.05
Freq.(GHz)

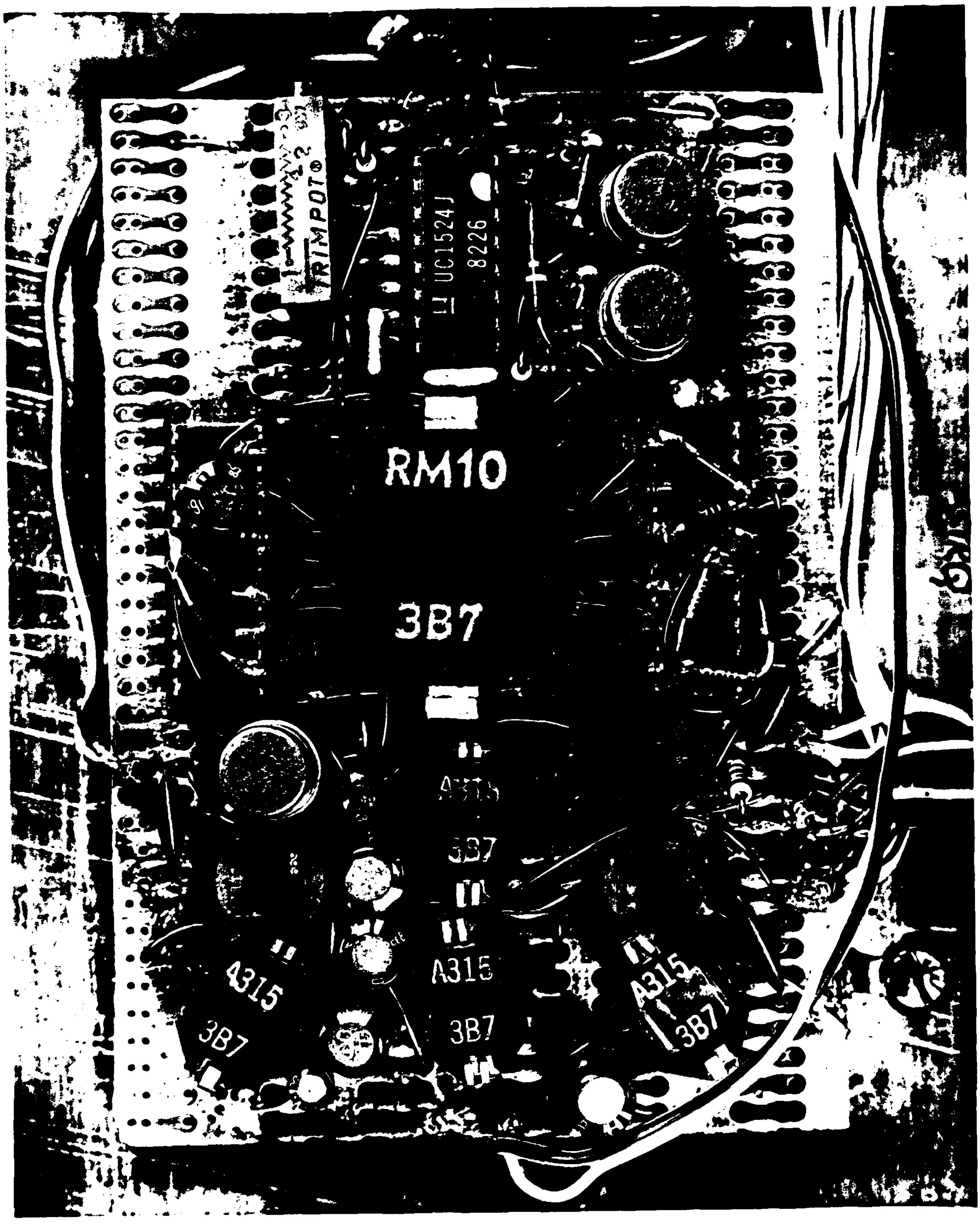

CM
0
2
3

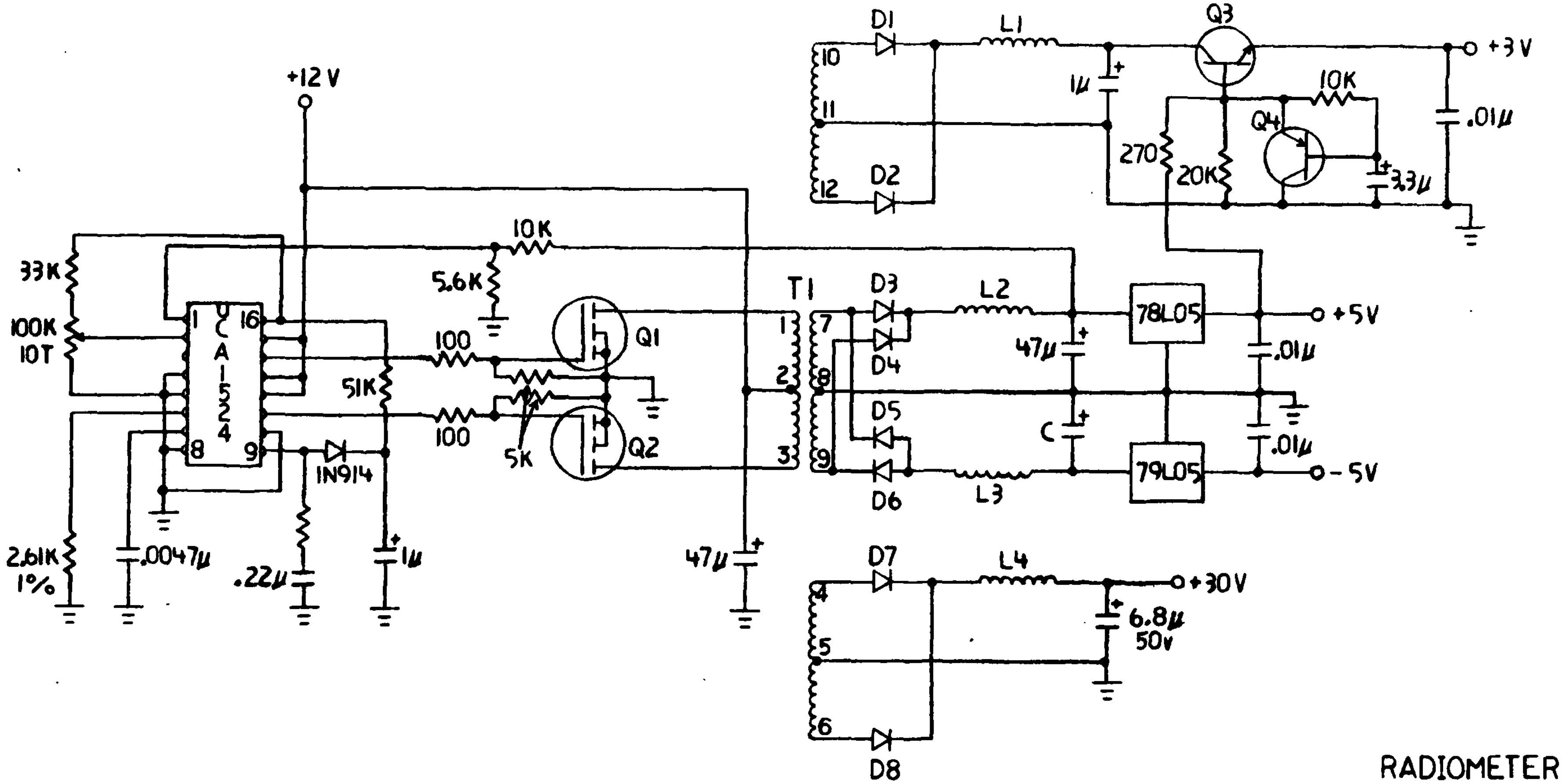

800-1
0 1 2 3
CM


42.0
40.0
38.0
36.0
34.0
Gain (dB)
3.7
3.8
3.9
4.0
4.1
4.2
Freq.(GHz)


UC1524J
8226


+31V
5
22µ
CA1524J
16
9
1
8
47µ
39K
.047µ
CNTRL IN
100K
PULSE OUT
TO P3-18
.82µ
100K
10T


UC1524J
8226
TRIMPOT
RM10
3B7
3B7
A315
4315
3B7
A315
3B7
A315
3B7

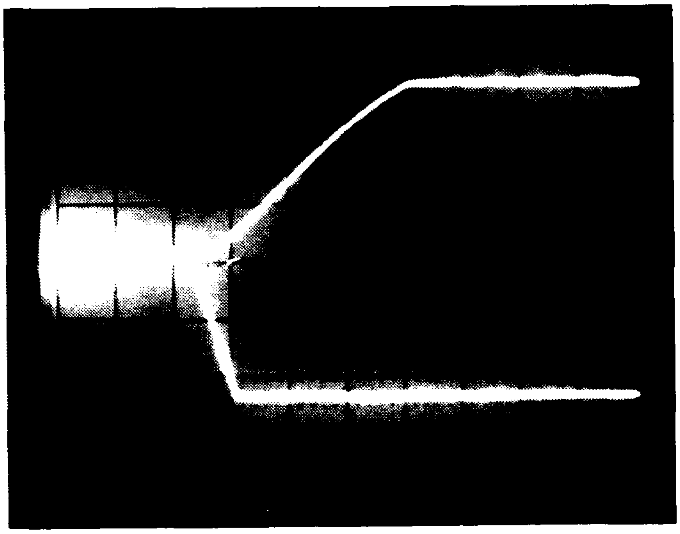



RADIOMETER SUPPLY
R. PAGLIONE
3-26-84

Q1, Q2 = RFL1N15
Q3 = 2N2102
Q4 = 2N4126
D1-D6 = 11DQ06
D7, D8 = UES1105
C = (2) 47µ in ||
L1 = 1mH (56T on RM5P-A315-3B7 Core)
L3, L2 = 10mH (178T " )
L4 = 58mH (436T " )

T1: RM10-3B7 Core
PRIMARY = 50T (1-2 & 2-3)
SECONDARY [+3V] = 20T (10-11 & 11-12)
" ±5V = 50T (7-8 & 8-9)
" +30V = 200T (4-5 & 5-6)

(a)



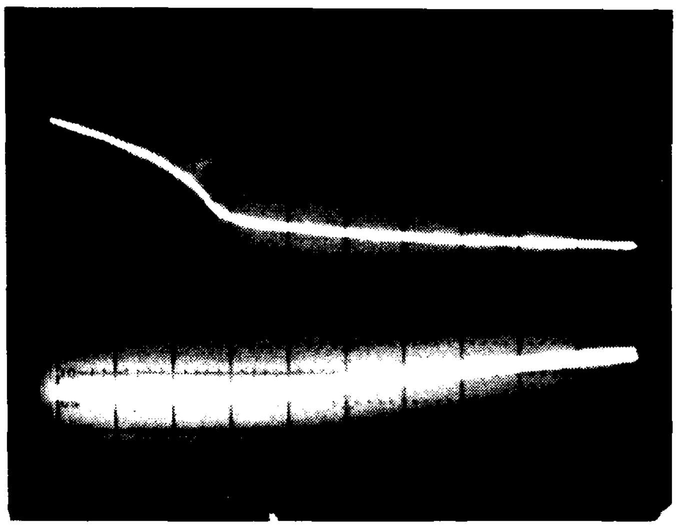
drain voltage
(1v/div)

gate voltage
(2v/div)

turn-on

time scale=20msec/div

(b)

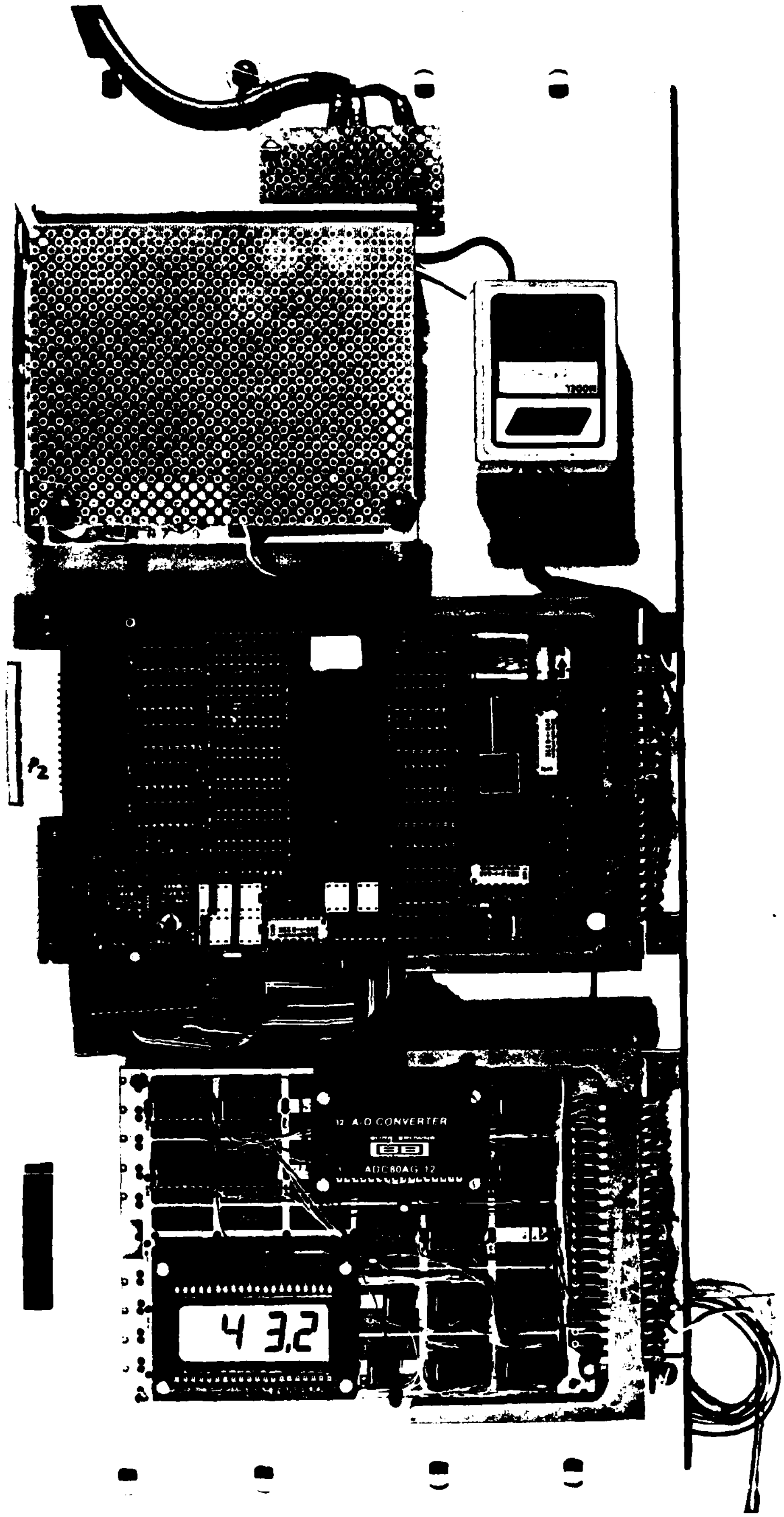


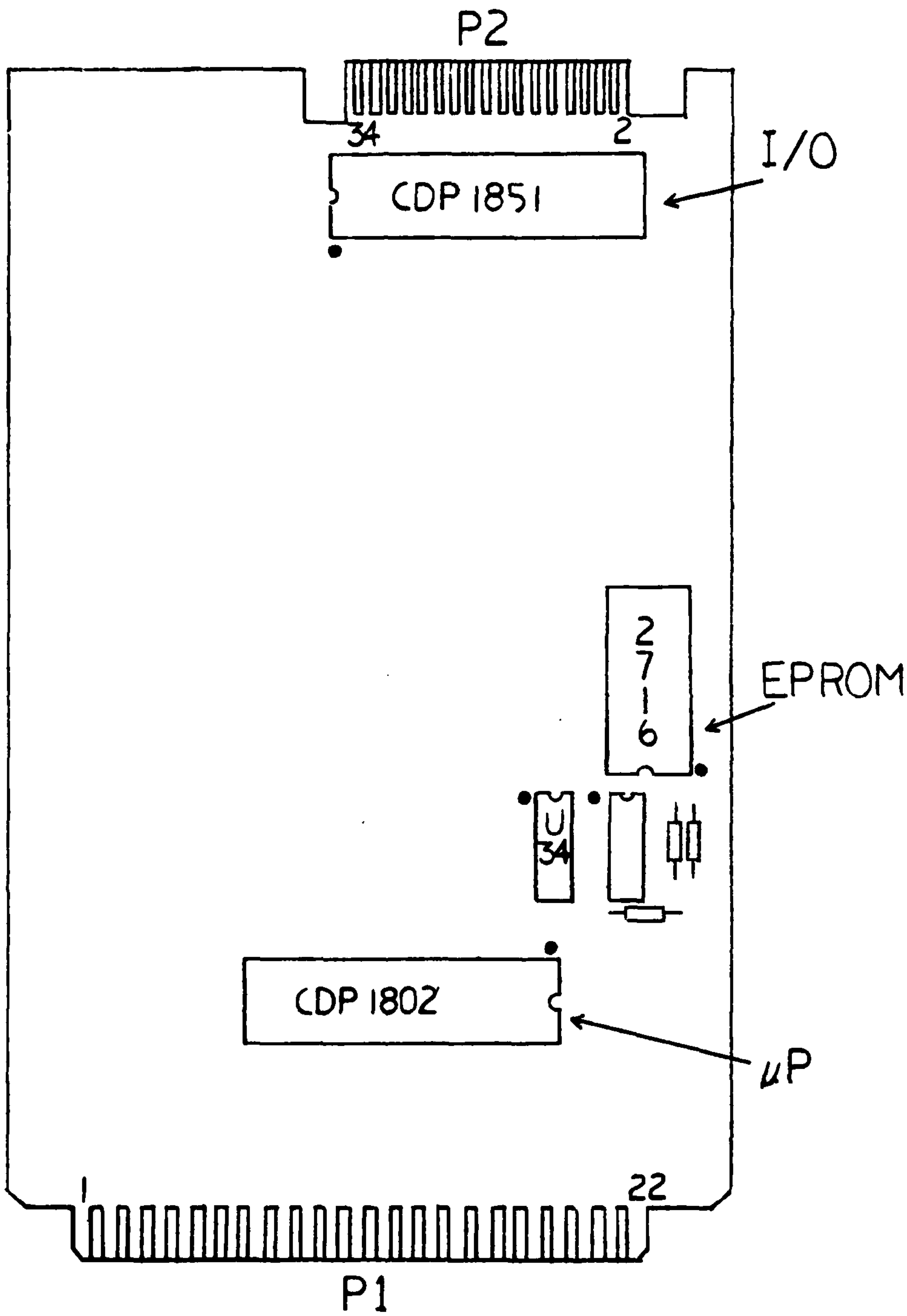
drain voltage
(1v/div)

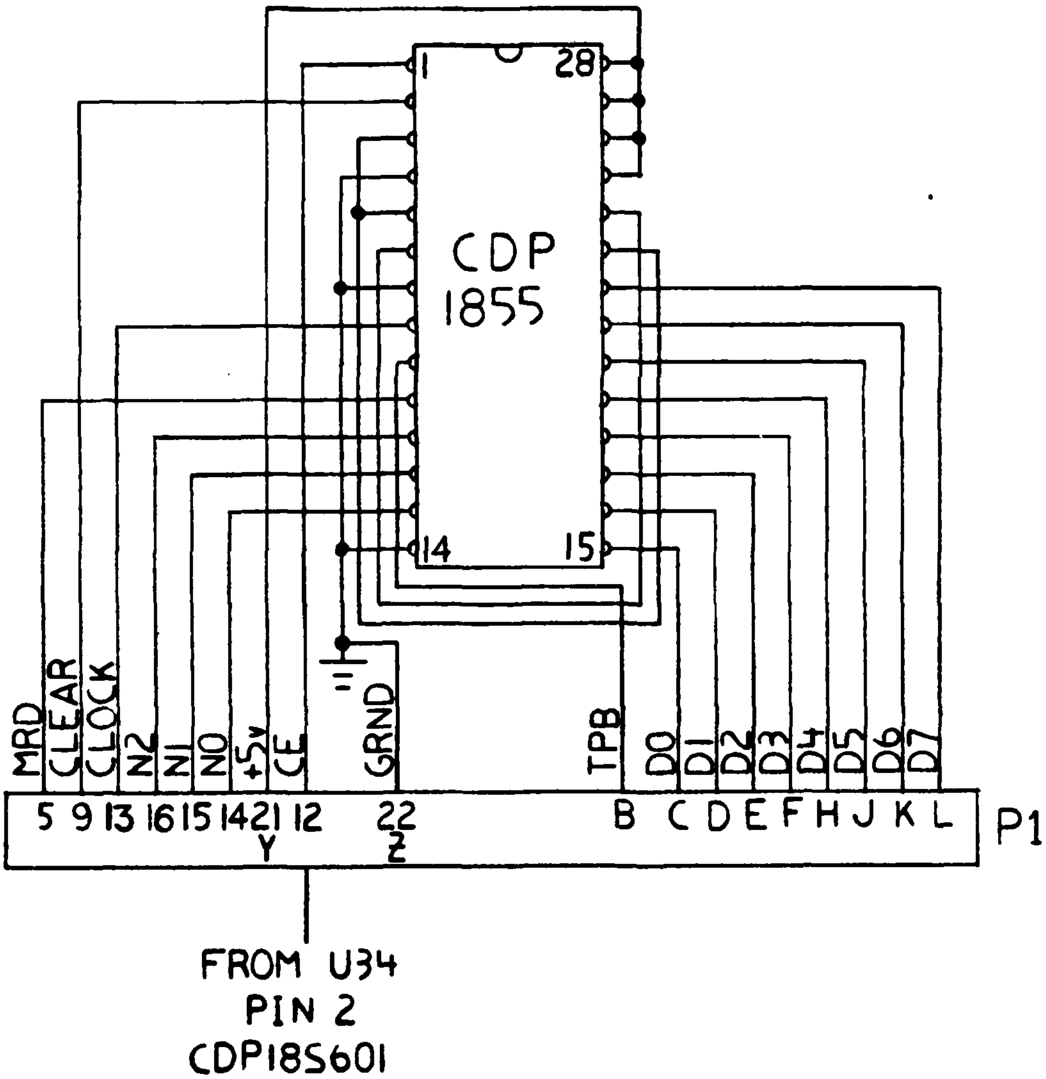
gate voltage
(2v/div)

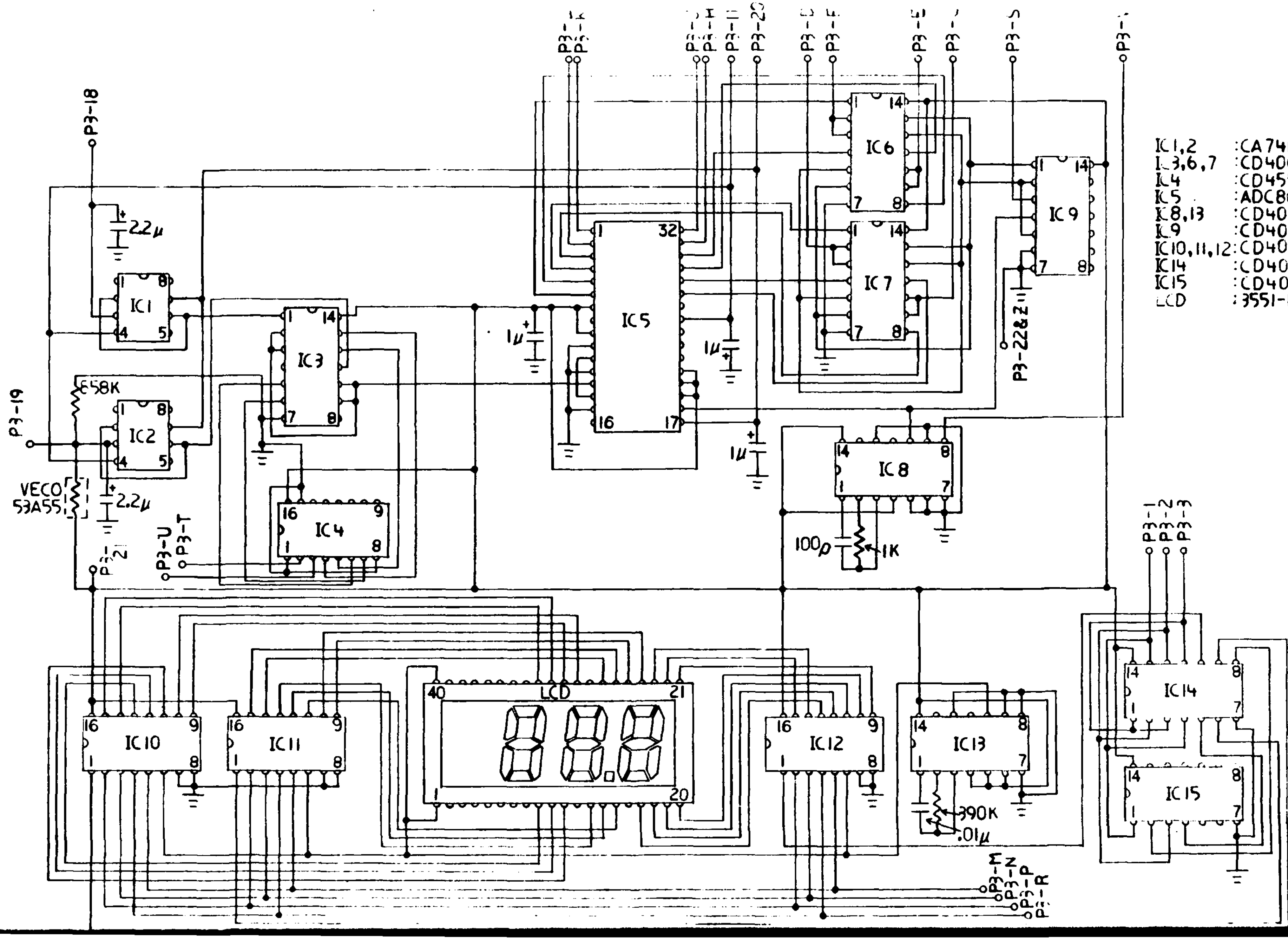
turn-off

time scale=2msec/div

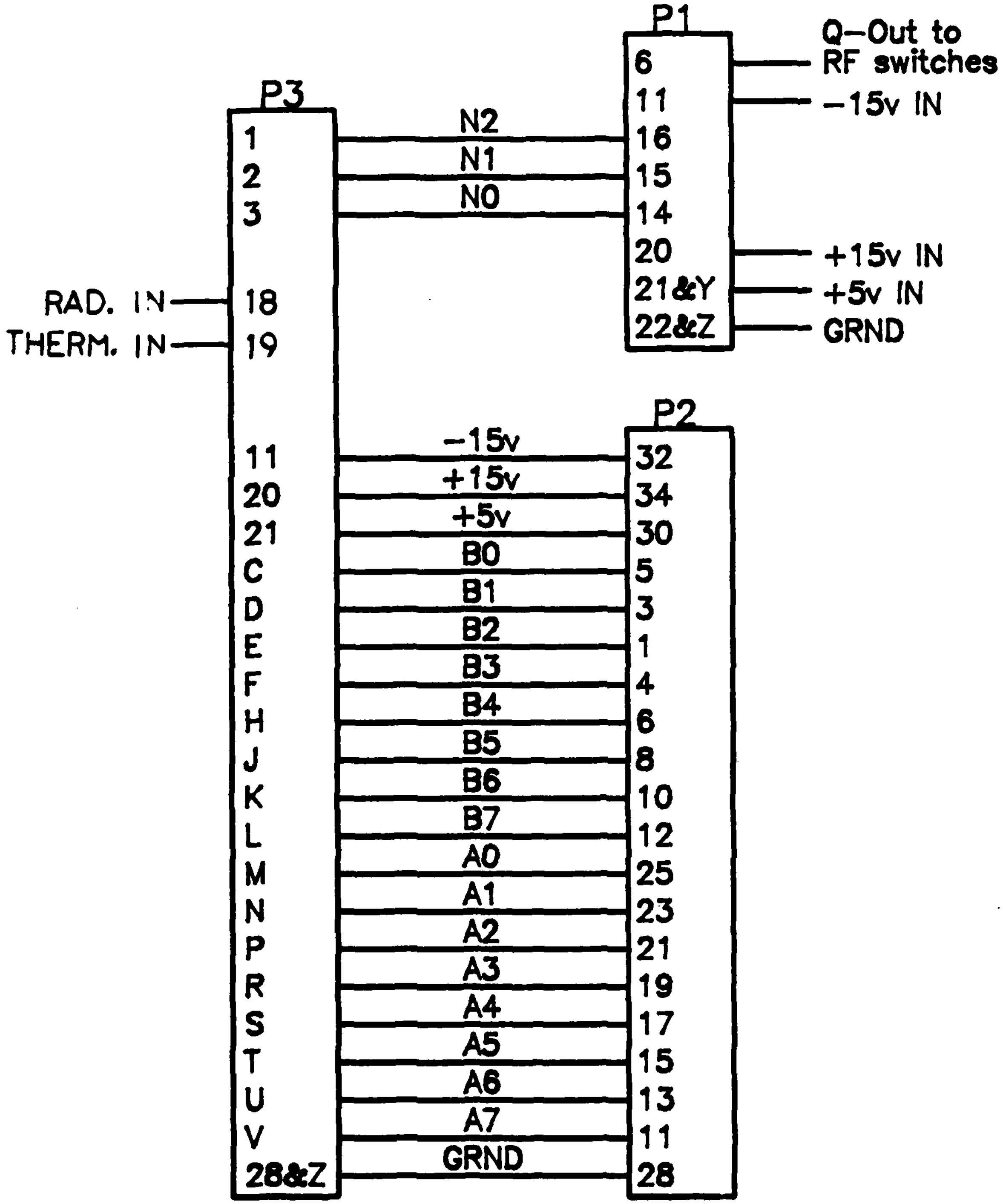

12 A-D CONVERTER
ADC80AG-12
43.2

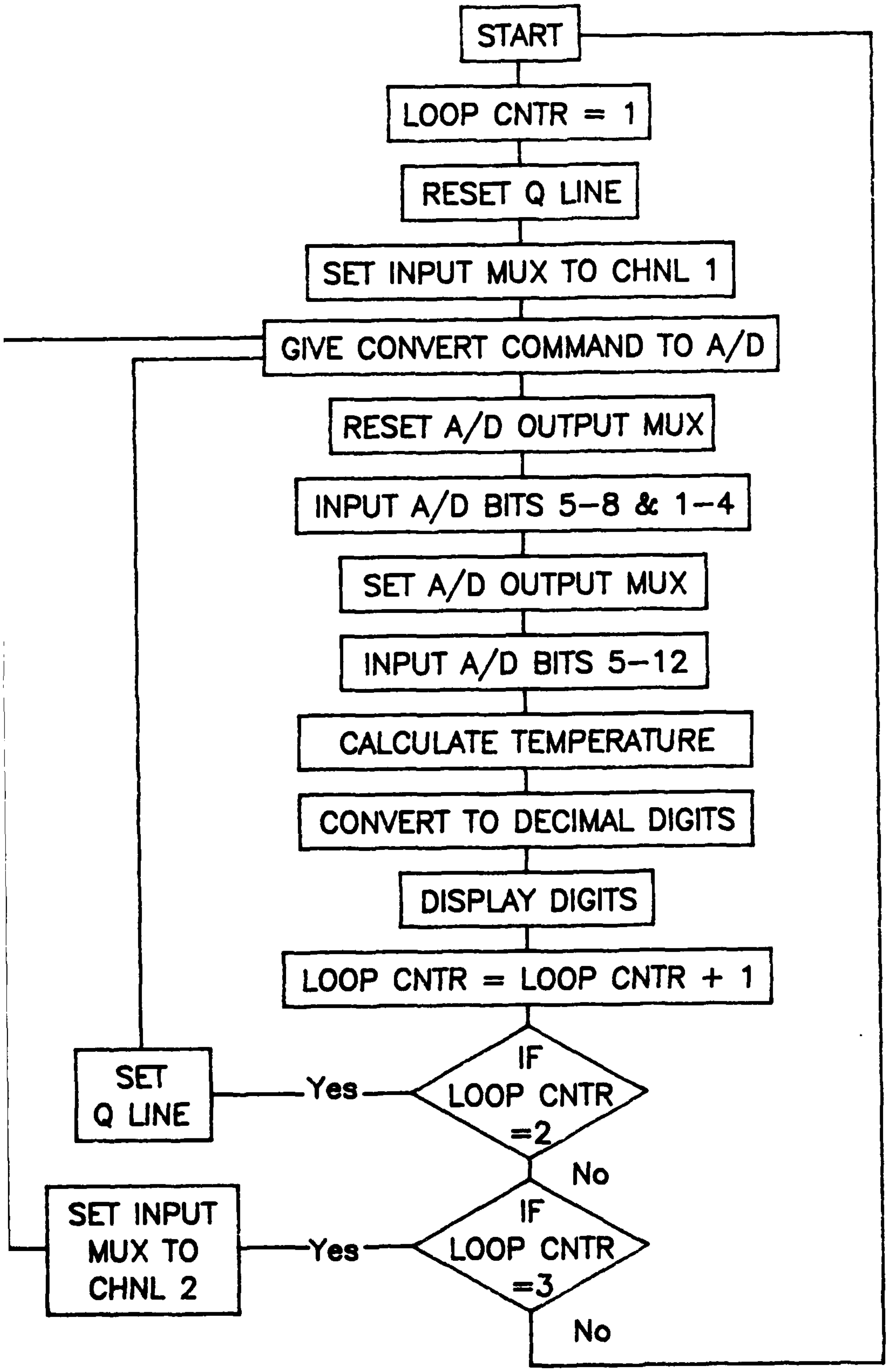

P2
34
2
I/O
CDP 1851
2
7
1
6
EPROM
U
34
CDP 1802
μP
1
22
P1

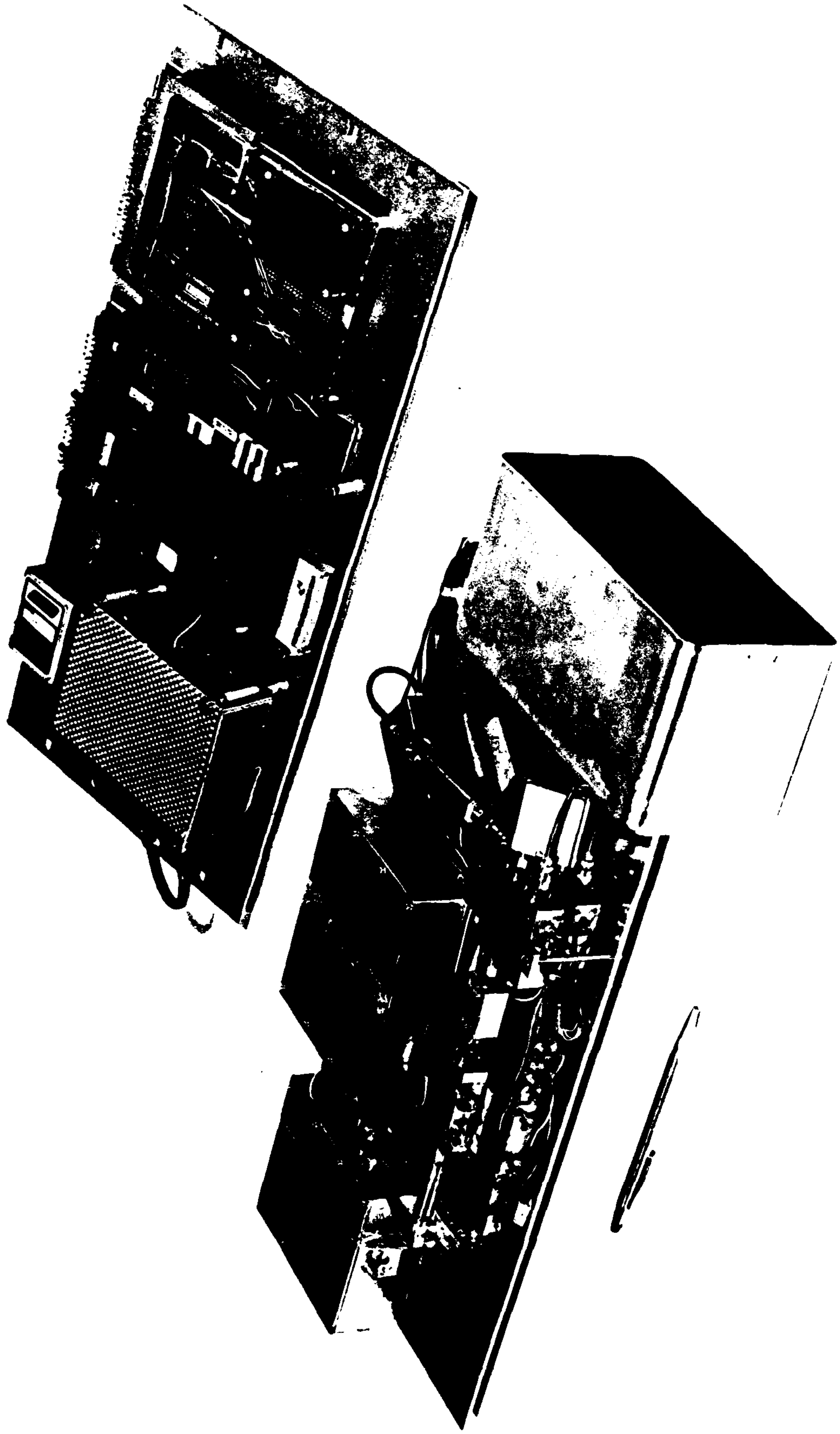

CDP
1855
1
28
14
15
MRD
CLEAR
CLOCK
N2
N1
N0
+5v
CE
GRND
TPB
D0
D1
D2
D3
D4
D5
D6
D7
5 9 13 16 15 14 21 12 22 B C D E F H J K L
Y
Z
P1
FROM U34
PIN 2
CDP18S601

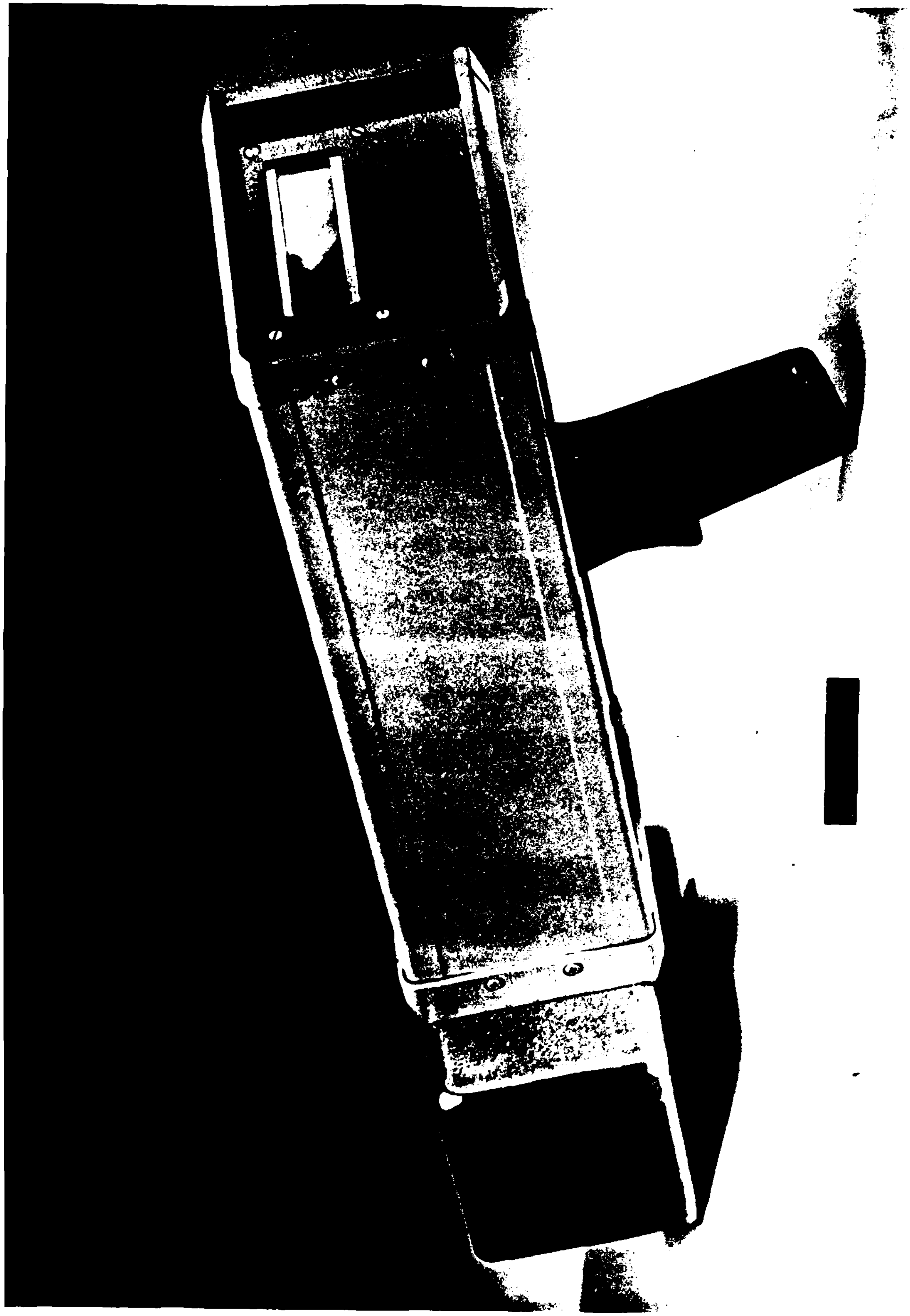



| | |
|---|---|
| IC1,2 | :CA741 |
| IC3,6,7 | :CD4066 |
| IC4 | :CD4555 |
| IC5 | :ADC80-12 |
| IC8,13 | :CD4047 |
| IC9 | :CD4013 |
| IC10,11,12 | :CD4056 |
| IC14 | :CD4073 |
| IC15 | :CD4069 |
| LCD | :3551-RPH-0 |


P1
Q-Out to
RF switches
-15v IN
+15v IN
+5v IN
GRND
P3
RAD. IN
THERM. IN
N2
N1
N0
6
11
16
15
14
20
21&Y
22&Z
1
2
3
18
19
P2
11
20
21
C
D
E
F
H
J
K
L
M
N
P
R
S
T
U
V
28&Z
-15v
+15v
+5v
B0
B1
B2
B3
B4
B5
B6
B7
A0
A1
A2
A3
A4
A5
A6
A7
GRND
32
34
30
5
3
1
4
6
8
10
12
25
23
21
19
17
15
13
11
28


START
LOOP CNTR = 1
RESET Q LINE
SET INPUT MUX TO CHNL 1
GIVE CONVERT COMMAND TO A/D
RESET A/D OUTPUT MUX
INPUT A/D BITS 5-8 & 1-4
SET A/D OUTPUT MUX
INPUT A/D BITS 5-12
CALCULATE TEMPERATURE
CONVERT TO DECIMAL DIGITS
DISPLAY DIGITS
LOOP CNTR = LOOP CNTR + 1
IF LOOP CNTR =2
Yes
SET Q LINE
No
IF LOOP CNTR =3
Yes
SET INPUT MUX TO CHNL 2
No





END

FILMED

9-85

DTIC